1-1-1991

Tactical Electronics Simulation Test System: Final Report CDRL A004

Michael A. Companion

Recommended Citation

Companion, Michael A., "Tactical Electronics Simulation Test System: Final Report CDRL A004" (1991). *Institute for Simulation and Training*. 187.
https://stars.library.ucf.edu/istlibrary/187

INSTITUTE FOR SIMULATION AND TRAINING

PREPARED UNDER CONTRACT NUMBER N61339-90-C-0125
for
NAVAL TRAINING SYSTEMS CENTER
and
NAVAL AIR TEST CENTER

TACTICAL ELECTRONICS SIMULATION TEST SYSTEM

Final Report: Phase I
CDRL A004

June 30, 1991

Institute for Simulation and Training
12424 Research Parkway, Suite 300
Orlando, FL 32826

and

Department of Electrical Engineering
University of Central Florida
Orlando, FL 32816

University of Central Florida
Division of Sponsored Research

IST-TR-91-21

TACTICAL ELECTRONICS SIMULATION TEST SYSTEM

FINAL REPORT

CDRL A004

JUNE 30, 1991

Prepared Under Contract Number 61339-90-C-0125

for

Naval Training Systems Center
and
Naval Air Test Center

University of Central Florida
Institute for Simulation and Training
12424 Research Parkway, Suite 300
Orlando, FL 32826

and

Department of Electrical Engineering
University of Central Florida
Orlando, Florida 32816

Prepared by:

Michael Compan
Michael A. Companion
Principal Investigator

Reviewed by:

RE Fairfield
Rupert Fairfield
Program Manager

TACTICAL ELECTRONICS SIMULATION TEST SYSTEM

FINAL REPORT

CDRL A004

JUNE 30, 1991

Prepared Under Contract Number 61339-90-C-0125

for

Naval Training Systems Center
and
Naval Air Test Center

University of Central Florida
Institute for Simulation and Training
12424 Research Parkway, Suite 300
Orlando, FL 32826

and

Department of Electrical Engineering
University of Central Florida
Orlando, Florida 32816

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

TACTICAL ELECTRONICS SIMULATION TEST SYSTEM
FINAL REPORT

ABSTRACT

This report addresses the preliminary findings of the Tactical Electronics Simulation Test System (TESTS) Phase I effort: Requirements Analysis and Feasibility Assessment. This first phase involved: (1) a determination of the requirements for an advanced IFF simulation environment; (2) determination of existing facilities and resources which are applicable and available to subsequent project phases; (3) assessment of technical issues and concerns to minimize risk; (4) and development of a technical approach and conceptual design for an advanced IFF system and environment simulation leading to TESTS.

Emerging IFF systems incorporate a number of operational modes and must function in a wide variety of tactical and environmental conditions. The MK XV IFF requirements specify almost a dozen functional modes, embedded MK XII modes 1 - 4 and C, multiple MK XV time dependent formats and subformats, Mode S and Radar Mode; a large number of environmental conditions, including ECM (benign, jamming), spoofing, weather/atmospheric, ground (over water, over land, near land), density, and platform variations; and a variety of operational conditions, including altitude configurations (High IR - High XP, Low IR - High XP, High IR - Low XP). Combination of these factors means that potentially, there are several hundred test cases to be considered. Simulation provides a cost effective and efficient way to subject the system to a large set of test conditions with accurately measured results. In addition to cost and efficiency considerations, some tactical conditions requisite to testing the system without simulation can be unsafe, impractical or impact security considerations.

A seven month extensive survey was conducted as part of the TESTS feasibility assessment to gather the data required to determine the feasibility of the TESTS concept, determine areas of research required to support the development and develop an initial design concept for TESTS. The survey included site visits to various government facilities, briefings on various IFF issues and review of an extensive collection of literature.

An analysis of the MK XV Test and Evaluation Master Plan (TEMP) was conducted to identify the performance requirements of TESTS. The analysis was based upon a review of the MK XV TEMP, the Navy inputs to the TEMP and briefing presented in September 1990 by NAVAIRTESTCEN personnel on IFF testing. The DRAFT U.S. Navy Input to the MK XV Identification Friend or Foe Combined Test Force Test Plan document, August 28, 1990, provided detailed insight on how TESTS might be applied during developmental test and evaluation. It provided details on the projected setup of test scenarios and conditions, and the interaction between various TEMP objectives. The focus of this analysis was five primary simulation TEMP objectives; Probability of Correct ID,

Anti-Jam, Interrogation Volume/System Capacity, Code Validation and Split Targets.

It appears technically feasible for TESTS to meet all five primary simulation TEMP objectives. System capacity and interrogation volume drive the TESTS design because of the number of platforms required. The TESTS recommended conceptual design provides a feasible approach to achieve these requirements in an effective manner. While it is not possible to achieve 100% fidelity, i.e., absolute emulation of the real world, in the TESTS design, it appears that all primary simulation TEMP objectives for TESTS can be achieved with high levels of fidelity. In addition, TESTS should be able to augment test and evaluation of a broad range of additional TEMP objectives.

Four basic approaches to implementing TESTS were examined. Based on this examination, an approach utilizing the Message Level Interface coupled with the modular channel effects hardware devices is the recommended TESTS approach. This approach provides an effective mixture of hardware and software implementation. Most importantly, the software computational requirements for MK XV data generation for large numbers of targets can be accommodated by generating data at a message level rather than the pulse level. The TESTS software is used to generate multiple transponder or interrogator signals via time division multiplexing, under control of the TESTS host computer. A number of separate signal generators may be easily added to increase the Reply rate or Interrogation rate capacity of the TESTS system. Programmable gain, phase, time delay and frequency distortion hardware devices will be used in a modular fashion to introduce channel effects in the generated signals. This separates the hardware functions, and allows for easier specification, design, testing and calibration of the equipment. It also provides for a more cost effective growth path to achieve the final TESTS capacity requirements, and it allows for greater flexibility in utilization of TESTS equipment.

In order to provide a low risk, high confidence, and cost effective approach to the design, purchase, fabrication, and integration of the hardware and software components of the TESTS system, an evolving Prototype Build Plan will be adopted. The plan utilizes a number of incremental builds which provide increasing capability and diversity in the number of platforms and signals to be generated, and simultaneously, increasing fidelity in the environmental and channel propagation effects to be simulated by TESTS. This evolutionary approach will allow early closed loop testing and validation of the TESTS system with existing IFF systems such as the MK XII, and provide a low risk transition to more advanced IFF systems utilizing spread spectrum signals.

The Navy's active support and cooperation ensured that the feasibility assessment was both comprehensive and thorough. The TESTS project team was permitted to study all relevant documentation and visit all pertinent facilities. Seemingly insurmountable technical obstacles diminished in difficulty as the team's knowledge increased. The conceptual design approach optimizes the TESTS to achieve identified TEMP objectives for an advanced IFF system utilizing a spread spectrum format. TESTS represents a significant, yet practical, advancement in the state-of-the-art simulation environment. A systematic research and development effort to determine parameter values for the channel effects and platform factors, e.g., antenna patterns, is required to realize the potential of the TESTS conceptual design. The essential conclusion is that TESTS will enable the Navy to address the five primary TEMP objectives identified for simulation and achieve accurate test results with high levels of confidence. In addition, TESTS should greatly improve the statistical confidence and accomplishment of a number of additional TEMP objectives.

1.0 INTRODUCTION

This report summarizes the findings of the Phase I effort: Requirements Analysis and Feasibility Assessment. The Tactical Electronics Simulation Test System (TESTS) project was envisioned from the outset to be a multi-phased effort wherein both technical and cost risk would be diminished during each successive phase. The first phase involved:

1. a determination of the requirements for an advanced Identification Friend or Foe (IFF) simulation environment,
2. a determination of existing facilities and resources which are applicable and available to subsequent project phases,
3. an assessment of technical issues and concerns to minimize risk, and
4. the development of a technical approach and conceptual design for advanced IFF system and environment simulation leading to TESTS.

The contract awarded to the University of Central Florida, Institute for Simulation and Training (IST) by the Naval Training Systems Center (NAVTRASYSCEN), Orlando, Florida was initiated on August 14, 1990. The Institute for Simulation and Training together with the Electrical Engineering (EE) Department are sufficiently confident in the feasibility of the required simulation and in the ultimate value to the U.S. Navy of acquiring such a simulation test tool that the discussion contained in this report will go beyond discussing technical feasibility issues and will also address a recommended technical approach which will lead to the cost effective development of the Tactical Electronics Simulation Test System (TESTS).

IST, a research organization dedicated to the advancement of simulation science and technology, has long been aware of the great value that simulation holds in the Test and Evaluation (T&E) of emerging systems. The Department of Defense has been particularly interested in the expanding role of simulation for T & E purposes. Major weapons systems, and their associated tactical electronics subsystems, have advanced technologically to the point where, if simulation science is not used, full and accurate test and evaluation cannot be conducted. Without full and accurate T & E activities in both the developmental and operational test phases, little confidence can be held in the predicted performance of either the major weapons system itself or its installed electronic subsystems.

This introductory section seeks to provide both a contractual and programmatic overview of TESTS prior to the technical discussion based on survey findings, requirements analysis, and feasibility assessment. The objectives of the initial phase of the project as documented in the finding of this report were:

1. to determine existing baseline capabilities at NAVTRASYSCEN and Naval Air Test Center (NAVAIRTESTCEN) applicable to the development of a tactical electronics simulation/stimulation model,
2. to determine the requirements and constraints for the development of a tactical electronics simulation/stimulation model,
3. to assess simulation technical risk issues,
4. to develop a conceptual design for a prototype model applicable to the IFF,
5. to conduct a feasibility assessment to ascertain that a MK XV IFF TESTS can be developed, that it can achieve test objectives, and that it represents a cost-effective solution and,
6. to develop a research plan for development of a prototype model.

1.1 PROBLEM

Emerging IFF systems incorporate a number of operational modes and must function in a wide variety of tactical and environmental conditions. The MK XV IFF requirements specify almost a dozen functional modes, embedded MK XII modes 1 - 4 and C, multiple MK XV time dependent formats and subformats, Mode S and Radar Mode Front End; a large number of environmental conditions, including ECM (benign, jamming), spoofing, weather/atmospheric, ground (over water, over land, near land), density, and platform variations; and a variety of operational conditions, including altitude configurations (High IR - High XP, Low IR - High XP, High IR -Low XP). The combination of these factors means that, potentially, there are several hundred test cases to be considered. Simulation provides a cost effective and efficient way to subject the system to a large set of test conditions with accurately measured results. In addition to cost and efficiency considerations, some tactical conditions requisite to testing the system without simulation can be unsafe or impractical because of degree of difficulty or security considerations.

When IST became aware of the MK XV IFF program, it became evident that it might represent an ideal candidate system for application of simulation technology in the T & E phases. Initial discussions with NAVAIRTESTCEN revealed that the U.S. Navy held similar opinions, but were concerned that such a simulation may not be feasible or once developed, lack credibility for the testing purposes required. IST requested a copy of the MK XV IFF Test and Evaluation Master Plan (TEMP). Of the 32 identified test objectives in the plan, it was evident that five critical objectives could not be achieved except through testing with simulation and that a large number of others could be tested with more confidence if a simulation test tool were developed. The practical goal of the T & E simulation thus defined, NAVAIRTESTCEN solicited comment from various key agencies to determine what technical obstacles and issues could hinder or prevent the cost effective development of the simulation test tool, now called TESTS. Comments by these key agencies were then consolidated into a listing of technical issues and concerns. These became the basis for the Phase I TESTS effort as reflected in both the contract and workplan.

With the cancellation of the MK XV the specific requirements for TESTS are currently less defined. However, the need for TESTS still exists, and may be more important than before. The Next Generation IFF (NGIFF) project is designed to replace the MK XV project. This project will build upon extensive lessons learned during the MK XV project and the Gulf War. While the design requirements of the NGIFF have yet to be developed, this project is expected to have a number of the technical issues encountered in the MK XV project. The developmental test and evaluation objectives are expected to be the same, though specific parameter levels may vary. Hence, the same requirements that identified a need for TESTS still exist in the NGIFF. TESTS could have more utility to the NGIFF, since it will be developed in concert with and earlier in the development process for NGIFF. Given its development as an integral part of NGIFF, TESTS, and tools developed as part of TESTS, could be used to evaluate design tradeoffs and assist in the development of the NGIFF specification. Futhermore, by considering TESTS early in the NGIFF project, the T&E activities for the NGIFF project should be facilitated because T&E requirements and provisions can be integrated into the NGIFF design.

One final important observation must be made. From the initiation of the TESTS project, an appreciation of three critical factors have been interwoven into every aspect of the approach used by the TESTS project team:

> Affordability - TESTS has to be cost-effective. A design-to-cost approach has been the project team's objective from the outset.
>
> Versatility - TESTS must serve the Navy's needs regardless of whether the final prime system were a MK XV or a MK XII enhanced IFF or any variation which might occur downstream. It must also make the best possible use of existing facilities, simulation tools, and equipment.
>
> Risk Reduction - Each successive project phase must reduce both technical and programmatic risk. An answer which solves one small piece of the problem without advancing the overall solution is never acceptable. No element of this project can be characterized as more than moderate risk and most of the technical issues have been reduced to low risk elements.

2.0 STUDY APPROACH

A seven month extensive survey was conducted as part of the TESTS feasibility assessment to gather the data required to determine the feasibility of the TESTS concept, determine areas of research required to support the development, and develop an initial design concept for TESTS. The survey included site visits to various government facilities, briefings on various IFF issues and review of an extensive collection of literature. The data collected and analysis of that data is reflected in the findings of this final report.

A total of ten site visits were conducted by various IST and EE technical personnel. The primary focus of the site visits focused on the facilities at NAVAIRTESTCEN. Four site visits were made to NAVAIRTESTCEN. During these visits initial and follow up discussions were conducted at each of the ACETEF laboratories, the IFF data center, and the Chesapeake Range Facility, among others. These visits provided the information required to assess current hardware and software capabilities at NAVAIRTESTCEN related to TESTS, future plans and resources, current practices and procedures, and points of contact that will be needed throughout the project. In addition to the visits to NAVAIRTESTCEN, additional site visits were made to NAVTRASYSCEN, Naval Electronics Systems Evaluation Agency (NESEA), Naval Research Laboratories (NRL), Kirtland AFB, and Bendix. These additional visits were conducted to gather information, clarify various technical issues and determine existing capabilities and resources which might be applicable to the accomplishment of the TESTS project objectives.

In addition to the information accumulated during the visits to various government and contractor facilities, six to eight additional briefings related to TESTS were conducted at IST by government representatives. In conjunction with the government briefings and site visits, over 90 technical documents totaling almost 3000 pages were reviewed regarding the MK XV, MK XII, Simulated Warfare Environment Generator (SWEG), Air Combat Test and Evaluation Facility (ACETEF) laboratories, etc. Based on the data gathered from these various sources, the UCF TESTS team was able to develop a thorough understanding of the operation of IFF systems, the requirements for TESTS, and potential approaches for the development and implementation of TESTS.

During the Phase I study, various supporting tools and/or implementation equipments were discovered that can be used to significantly reduce the time and money expenditure to produce a simulation tool. Among these items are:

1. software configuration management system,
2. various software packages for use in analysis of channel effects,
3. Bendix MK XV modified ADM test equipment (residual of

AF MK XV Program),

4. Object oriented ADA packages, and

5. RF signal generation equipment, multichannel, for threat simulation (CAL CORP.).

2.1 SUMMARY OF MAJOR SURVEY FINDINGS

Existing capabilities within ACETEF and other laboratories at NAVAIRTESTCEN reduce the development requirements for TESTS. While simple models will need to be developed or procured to support TESTS validation and testing of the design, TESTS will be designed to make use of existing resources to the maximum extent possible. ACETEF provides initial capabilities for required ECM environments, scenario control, data capture and other facets as described above. Some capabilities, such as ECM do not currently include the necessary advanced jamming capabilities. However, these capabilities are planned and will be available by the completion of the TESTS implementation.

The computer and network hardware environments are predominantly VAX and SUN based and use industry standard interfaces/bus architectures. These computer environments provide a relatively standard and open architecture. This will simplify the integration of TESTS into ACETEF and should not impose any significant cost burden to the program. The use of SUN computers offers the opportunity to implement TESTS using a distributed or federated approach. High-speed, low cost coprocessors are available for this environment which permit a very cost effective computer environment for TESTS. This environment is easily expandable to accommodate increased or unexpected processing requirements and future growth. Hence, we do not perceive that the implementation of TESTS within NAVAIRTESTCEN facilities imposes any technical risk.

One area which TESTS must address is signal generation capabilities for spread spectrum type signals. Current facilities at NAVAIRTESTCEN cannot adequately support this requirement. Several viable methods for developing this capability within TESTS are being studied. Cost and schedule will probably be the criteria used to determine the most effective approach. Jammer capabilities within EWISTL and EMEGS can be easily interfaced to TESTS.

The area of greatest concern is SWEG. This is the required interface for TESTS and the primary source of simulation control. The Navy version of SWEG is still in development and the final level of capability is still undetermined. SWEG is derived from a battlefield simulation called SUPPRESSOR which is approximately ten years old. The ability to upgrade or modify any software package that old represents a degree of technical risk. Short cuts also tend to be adopted in updating software which might compromise performance if not fully tested. For example, SUPPRESSOR utilized metric conventions for all units, i.e., meters rather than feet. Selected parts of SWEG have been modified to use english units, i.e., feet. This is necessary since most of the Navy's measurements are in feet. However, an examination of the SWEG source code indicates that not all units have been changed, only those directly related to certain input parameters. Hence, there is a mixture of measurement units in the current version of SWEG. Conversion between units within SWEG could introduce an unknown degree of error simply because of round off errors. There will also be a need to supplement SWEG with a TESTS specific data base. SWEG appears to have the basic capability to support TESTS and provides as much fidelity as any available scenario simulation package. However, until SWEG is fully upgraded and validated within ACETEF, it represents a potential impact on TESTS.

2.2 SUMMARY OF TEMP OBJECTIVE ANALYSIS

Analysis of the MK XV Test and Evaluation Master Plan (TEMP) objectives was conducted to identify the performance requirements of TESTS. The analysis was based upon a review of the MK XV TEMP, Navy inputs to the MK XV Combined Test Force, and a briefing on IFF test procedures by NAVAIRTESTCEN presented in September 1990. The DRAFT U.S. Navy Input to the MK XV Identification Friend or Foe Combined Test Force Test Plan document, August 28, 1990, provided detailed insight on the manner in which TESTS might be applied during developmental test and evaluation.

The focus of this analysis was five primary simulation TEMP objectives identified for TESTS by the Navy. These primary TEMP objectives for TESTS include:

probability of correct ID,
anti-jam,
system capacity/interrogation volume,
code validation, and
split targets.

The goal of TESTS is to maximize the ability to meet these five objectives. These five objectives were identified as requiring simulation to adequately test due to cost, the high number of simultaneous aircraft required, repeatability concerns, safety, and OPSEC.

Not all of the thirty-two MK XV TEMP objectives are relevant to the TESTS project, e.g. Logistics Supportability and Safety. However, while not a specific requirement, TESTS should also provide the capability to assist in the evaluation of a number of other TEMP objectives, hereafter called secondary TEMP objectives. This may provide secondary cost benefits through reduction of flight test hours, or provide additional data to enhance the test and evaluation findings. Flight tests can only sample a small subset of data points from the possible combinations of all parameters. A simulation/stimulation test tool can supplement flight test data by providing a high density environment for all objectives as necessary, large data samples and a much richer combination of test conditions covering altitude configurations, modes and formats, physical environments, ECM conditions, PRFs and scan rates and Reply/Interrogator densities. Secondary TEMP objectives which might benefit from TESTS include:

maximum range,
minimum range,
range resolution,
range accuracy,
azimuth resolution,
azimuth accuracy,
FRUIT rate,
diversity performance,
multipath performance,
anti-spoof,
crypto,
interoperability & compatibility, and
electronics counter measures (ECM).

An analysis of the applicability of TESTS to the relevant subset of TEMP objectives was conducted. Of the five primary TEMP objectives that TESTS was formulated to address, it appears that all can be technically met. System capacity/interrogation volume drive the TESTS design because of the number of platforms required. The TESTS conceptual design addressed in later sections provides a feasible approach to achieve these requirements in an effective manner. The ability to meet the anti-jam objective will require additional capability in a stand alone configuration, however, off-the-shelf systems are available which provide that capability. The accomplishment of the anti-jam objective in a stand alone configuration is therefore a cost decision. While it is not possible to achieve 100% fidelity, i.e., perfect emulation of the real world and all its variations, in the TESTS design, it appears that all primary TEMP objectives for TESTS can be achieved with high levels of fidelity. The scheme for introducing propagation effects proposed for TESTS will require a systematic direct research to determine appropriate parameters and levels of fidelity, however, it appears technically feasible and within cost boundaries.

The key is selective levels of fidelity. Selective fidelity emphasizes choosing the lowest level of fidelity which provides realistic test conditions and appropriate system performance impact. Different levels of fidelity may be selected for every factor in the design, i.e., high levels of fidelity are chosen for critical factors and lower levels of fidelity are chosen for those factors which impose little impact on system performance. For example, consider the number of multipaths. In the real world there may be N multipaths, but it may not be necessary to simulate all possible multipaths to have a realistic system. The objective is to include the minimum number of multipaths which subject the system to a realistic degrading impact of multipath. For the MK XV the maximum number of multipaths that could impact the system is bounded by the COMSEC and TRANSEC characteristics and the db cutoffs of the system. Only when the multipath signal falls within the correct interval or is of sufficient intensity will it be accepted. Other multipath signals are irrelevant to the simulation. However, within the pool of acceptable multipath signals, not all have the same degree of impact. From a simplified view, the potential impact of each successive multipath becomes less because of reductions in gain, etc. If the system can reject the first few strong multipath signals, it should be able to reject all subsequent multipath signals. Hence, to test the resistance to multipath effects, it is only necessary to subject the system under test to those which have the greatest probability of impacting system performance. As a result, a simulation approach to multipath requires a minimum of one multipath to provide the basic impact of the variable. This provides the largest increment of the potential impact on system performance. The maximum number of additional multipath signals required is determined by examining the asymptotic trends of the signal characteristics. The recommended TESTS approach splits the generated signal/message into a primary signal and multipath signal(s) which are modified by channel effects. The operation of the hardware/software channel for both types of signal is the same. This common configuration permits the number of multipath signals to trade off with the number of platforms, i.e., as the number of platforms increases the available number of multipaths per platform decreases. The minimum acceptable configuration provides for one multipath signal per platform at the maximum number of platforms in the systems specification. One of the supporting research tasks for TESTS is to determine whether more than one multipath signal per platform must be included in the baseline configuration. The recommended design permits this baseline capability to be easily expanded, though the cost of expansion increases exponentially.

In addition to the primary TEMP objectives associated with TESTS, TESTS should be able to augment test and evaluation of a broad range of secondary TEMP objectives. The basic capability required for these secondary objectives are a subset of the parameters which must be included in TESTS to achieve acceptable levels of fidelity on the primary TESTS TEMP objectives.

2.3 TECHNICAL ISSUES

During this assessment, extensive interchanges were conducted with NAVAIRTESTCEN technical representatives in order to maximize the outcomes of the activity. The EE Department took the lead in examining technical risk issues regarding signal processing requirements for TESTS and the potential for modeling various propagation effects. These analyses are required to maximize the fidelity of TESTS and enhance the eventual validation and verification of the models incorporated in TESTS. IST took the lead in the development of the TESTS conceptual design and the procedures that will be followed during TESTS development and implementation. A joint effort between the two groups was pursued in the analysis of signal simulations approaches and the development of signal generation concepts.

Ten specific technical risk issues were identified for the feasibility assessment. Each of these issues is addressed below. References to supporting discussions in other sections of the report are indicated in each response as appropriate.

2.3.1 MK XV Time Dependent Formats

A communication system consists of a transmitter and receiver; one means of mechanization of Time Dependent Formats (TDF) in a cooperating communication system requires that the transmitter and receiver parameters will vary in time and be synchronized.

Typical transmitter and receiver models were formulated using a time dependent PN sequence as a method to modulate a signal wave form. The modulation generates signals in time as a function of both the time varying message data and the time dependent modulation control signal. The time dependent control signal is generated through the interpretation of time dependent code sequences which are, in turn, generated from a time dependent code generator.

The simulator computer can synthesize a fixed field of PN sequences and transmit it to the System Under Test (SUT), as well as other friendly emitters, while synchronizing all sequences to the simulator time reference. The spreading or despreading process is therefore controlled by masking (in real-time) the coefficients of the primitive polynomial with the PN sequence to yield the appropriate modulation for the process as a function of time. This method of simulator implementation would provide early testing of SUTs without the necessity of using the KI-15 equipment.

2.3.2 Rapidly Changing Masking Functions

Masking functions are used in the signal processing scenario of the Mark XV IFF System. It is usually implemented by merging two binary fields (using basic instruction set commands); it minimizes computer computation time requirements.

The spreading sequence of a spread spectrum waveform is particularized by taking the complement of an "EXCLUSIVE OR" command, bit by bit across the field of PN control sequences and the field of coefficients of the primitive polynomials for each change in time.

Time dependent masking will be implemented in the simulator tool and specifically in the waveform generation subsystem. The use of the Bendix waveform generation equipment for the implementation of the simulator tool also would use masking techniques (already implemented) for conditioning the waveform through all of the IFF MODES of operation.

2.3.3 COMSEC Validity Interval

The COMSEC validity interval changes at a rapid rate in the MK XV/K-15 system. MK XV system performance is totally dependent upon the validity of the COMSEC interval. If the COMSEC validity interval is not synchronized between TESTS and the SUT, then it will be virtually impossible to generate valid system data. System errors would be a function of the timing desynchronization, not MK XV capability. During the testing of the ADM it was necessary to develop a portable time calibration device to achieve acceptable synchronization between test systems.

The NSA has indicated that they would make available the interface (pin-out) information for the K-15 as they have for the KIT/KIR. The impetus for this problem came from the difficulty in synchronizing the ADM with the PUT during flight testing of the ADM, where a custom portable time synch unit had to be developed. This has potential application to solve this problem in TESTS. However, TESTS has an advantage over the ADM testing in that the TESTS tool and the PUT will be in close physical vicinity. TESTS and the PUT will already have a certain degree of hard wire interfacing to support data collection. With the information available from NSA the simplest solution is to interface both TESTS and the K-15 of the SUT to a common external clock source. Driving both TESTS and the SUT from the same time source will therefore ensure proper synchronization.

The synchronization requirements for the COMSEC interval in TESTS can best be achieved by linking both TESTS and the K-15 of the SUT to a common source. Information obtained during the survey indicates that the required technical data will be made available as needed. This will require close coordination with the NSA to select the most acceptable and technically feasible approach.

2.3.4 MK XV IFF Radar Mode

The simulation tool will be required to stimulate only radar mode transponders. Therefore, the Interrogator Simulator Tool (IST) portion of the simulation tool needs to be synthesized. The differences in the MK XV IFF RMFE waveform processing must be analyzed and related to the requirements for the IST.

The modulation/carrier frequency for the IFF RMFE are at X and S-Band vs L-Band for the other IFF modes. The waveform format and processing functions for the RMFE is also quite different than the format used in the L-Band modulation protocols. These differences suggest that a separate processing channel be used to satisfy the RMFE Interrogator Simulator Tool (IST) requirement.

2.3.5 RF Generation of Spread Spectrum Signals

The MK XV IFF system utilizes spread spectrum signals to enhance communication performance and security. Spreading information in the frequency domain inherently requires shrinking of pulse widths, called chips, in the time domain. The high chip rates associated with spread spectrum signals of interest would require enormous processing speeds in order to perform convolutions and correlations on these signals in a simulation environment in real time. Computer simulation of real time spread spectrum systems will typically require giga-flop processing speeds, while hardware implementations require less than 100 MHz clock rates on the fastest components.

Therefore the recommended implementation of a TESTS system requires the use of hardware components to perform the actual spreading and despreading operations, and to let the superposition of overlapping signals occur in the hardware channel at RF carrier frequencies. The TESTS host computer will manipulate IFF messages at baseband information levels, and communicate such information to the TESTS hardware signal generation devices.

2.3.6 RF Generation of Multiple Spread Spectrum Signals

MK XV TEMP Objectives require the testing of the IFF system in realistic scenarios where many additional transponders and interrogators will be operating simultaneously. This leads to high interrogation rates if the SUT is a transponder, or high total reply rates if the SUT is an interrogator. Interrogation rates on the order of several thousand per second, and reply rates on the order of 30 thousand per second are possible in these test scenarios. These rates stress the computational capacity of the TESTS host computer, and require that multiple RF signal generators be incorporated in order to realistically simulate a high density signal environment at the receiver of the SUT.

Further analysis and refinement will be performed, using a realistic mix of message lengths, and simulating a realistic distribution of interrogators and transponders. The overriding consideration for this analysis is that if spread spectrum waveforms are mixed, the content of each message cannot be extracted unless one of the messages is known. This requires separate signal generators to preclude overlapping signals. These results do indicate, however, that a finite and feasible number of RF signal generators (approximately 2 to 10) can be used in the recommended TESTS approach to achieve the signal density environments required by the proposed test scenarios.

2.3.7 Simulation of Multipath Propagation Effects

Multipath propagation effects are caused by the interference of a reflected electromagnetic waveform with the primary, direct path waveform at the receiver. The reflections are often caused by the surface of the earth, although man-made objects and sometimes tropospheric reflections may contribute to multipath effects. The interference at the receiver may be either constructive, or destructive, and depends upon the gain, phase, frequency shift, and time delay of the reflected signals relative to the direct signal. Multipath effects are a part of the real world RF communications problem, and depend upon many parameters such as the geometry of the transmitting and receiving platforms, the electromagnetic properties of the reflecting surface, and the type and complexity of the intervening terrain.

To alleviate TESTS host computer processing loads, and to provide accurate, credible superpositioning of direct and reflected path signals, the recommended TESTS concept uses separate, parallel hardware channels (split from a common signal/message input) within the RF Signal Conditioner to represent the direct and multipath signals. A separate set of programmable time delay, gain and phase distorters will be provided in hardware to represent the indirect signal, which is summed in the hardware channel with the direct path signal and presented at the RF receiver of the PUT. Based upon conditions of the test scenario, TESTS software components will compute the equations and algorithms for the multipath effects to determine the appropriate gain, phase, and time delays to transmit to the hardware distortion devices. This approach appears both feasible and cost effective.

2.3.8 Reception and Processing of TDFs

A description of the reception and processing of TDFs is sought. Identification of the processes and timing considerations are needed to relate the TDF issues. The receiver processes are analyzed to relate the sensitivities of the TDFs to fidelity of the data capture.

The reciprocal process of demodulation, decode and identification follows inversely the waveform generation, the TDF and masking discussions above. It was found that the PN sequence mask must be synchronized to the received waveform in order to despread the spread spectrum signal and recover the data correctly. Timing was found to be extremely sensitive to correct data capture.

The implementation of the Bendix Test equipment, namely, the receiver subsystem, has already mechanized the demodulation and decode processes. If Bendix equipment is not available, other hardware can be purchased and modified to implement this process. Using this subsystem along with the synchronized PN sequences (TDF) that are centrally generated by the simulator computer, the implementation of the simulator tool can be made much easier.

2.3.9 Near Field Effects

The <u>near</u> <u>field</u> <u>effects</u> of an antenna relate to the modification of the radiation pattern by the close proximity of various objects or other antenna to the transmitter. Various models are used, namely, "New-Air", INAC-3, GEMACS, and STRIPES, to analyze the near field effects of interrogator geometries, antennae placements (diversity systems), and to give antenna pattern functional relationships for a range of IFF platforms.

It has been determined that particular state-of-the-art models can be used to quantify the following near-field effects:

1. "New-Air" Code can be used to find near field patterns of antenna mounted on aircraft or missiles. This program which is a high frequency model will be used primarily to predict near field effects. This code has been developed at Ohio State University.

2. GEMACS is a hybrid method. It combines both the Geometrical Optics (GO) approach and the method of moments.

3. STRIPES is based on the transmission line method and is not intrinsically limited in frequency. The only requirement is that the physical space of the platform is modelled by a mesh with resolution no coarser than 10 cells per wave length.

All the above listed programs have been used to access their value. The ranges and functionality have been determined to be appropriate to the needed fidelity and to model the near field antenna patterns required.

2.3.10 Modeling of Antenna Pattern Effects

Computer Models are necessary to relate the parameter of "antenna gain" to all aspects (azimuth and pitch angle) of the various platforms under study.

In order to have any kind of relation with real world performance, the antenna characteristics have to be incorporated on the stimulation signal. The near field and far field patterns can be incorporated in terms of power, gain, directivity, phase and polarization. The stimulated signal will depend on the efficiency and gain of the transmitting and receiving antenna. The models identified (Section 2.3.9), have been used to access the fidelity of the needed antenna patterns. The angular resolution needed to accurately model the antenna gain is one degree (1°) in both azimuth and pitch. Since the computation time of this parameter must be kept minimal, a table look-up file will be used to implement the antenna gain factor into the real-time computer algorithm.

The generation of the computer models for antenna gain have been analyzed to the extent that a method of real-time implementation is formulated. The need and unique ability of simulation modeling to easily generate three dimensional antenna patterns is critical to TESTS. The collection of real antenna pattern data in three dimensions requires difficult to impossible maneuvers for an aircraft to only partially measure the vertical components of antenna gain. A case for "simulation"!

2.4 LESSONS LEARNED

During the course of the Phase I feasibility assessment, three issues were encountered that provide significant lessons learned related to the full development of TESTS for the NGIFF. These issues include:

1. the critical impact of SWEG on TESTS,
2. the need for an early and increased influence of T&E on the NGIFF, and
3. the importance of validation and verification to TESTS.

The salient aspects of each of these issues is discussed below.

2.4.1 SWEG

One of the critical areas that must be given careful consideration is SWEG. The primary interface of TESTS to the other components of ACETEF required during testing will be provided by SWEG. An outgrowth of the SUPPRESSOR simulation program, SWEG has been updated to control and coordinate tactical engagement simulations in ACETEF, and provides a rich library of platform and emitter models. SWEG provides a standard format for the shared memory interface between the various components of ACETEF, and defines the protocol for interactions between components. The software components of TESTS will interface to the SWEG shared memory for required scenario simulation data, such as platform positions, attitudes, velocities, terrain elevation data, antenna pattern directional attenuations, antenna scan rates, etc. Note that TESTS will utilize some subset of SWEG capabilities to provide scenario preparation and execution, even when operating in a stand alone configuration in the shielded hangar. It is anticipated that all interactions between TESTS software components, and other components of ACETEF, will take place via the SWEG shared memory interface.

The Navy version of SWEG is still in development and the final level of capability is still undetermined. SWEG is derived from a battlefield simulation called SUPPRESSOR which is approximately ten years old. The ability to upgrade or modify any software package that old represents a degree of technical risk. Short cuts also tend to be adopted in updating software which might compromise performance if not fully tested. For example, SUPPRESSOR utilized metric conventions for all units, i.e., meters rather than feet. Selected parts of SWEG have been modified to use english units, i.e., feet. This is necessary since most of the Navy's measurements are in feet. However, an examination of the SWEG source code indicates that not all units have been changed, only those directly related to certain input parameters. Hence, there is a mixture of measurement units in the current version of SWEG. Conversion between units within SWEG could introduce an unknown degree of error simply because of round off errors. There will also be a need to supplement SWEG with a TESTS specific database. SWEG appears to have the basic capability to support TESTS and provides as much fidelity as any available scenario simulation package. SWEG is undergoing significant modification under contract to the CNIL. Variables are being added which will permit communication and IFF systems to be specified more precisely and the coordinate system is be modified to a polar system to accommodate satellite players within the scenario, i.e., SATCOM, etc. The CNIL version of SWEG should be used for TESTS. Until SWEG is fully upgraded and validated within ACETEF, it represents a potential unknown impact on TESTS. Hence, modifications of SWEG will need to be closely monitored. Furthermore, the documentation on SWEG is somewhat limited, so TESTS researchers will need to discuss SWEG operations directly with BDM personnel to ensure that SWEG is fully understood.

While TESTS can operate in a stand alone configuration or integrated through CNIL to ACETEF, SWEG will always be required. In the stand alone configuration SWEG will need to be hosted at a workstation level, such as a VAXstation. When integrated with CNIL/ACETEF, TESTS will receive SWEG inputs through the appropriate level of shared memory. In the CNIL/ACETEF integrated configuration TESTS may require two interfaces to the shared memory. In order to meet real time processing requirements for multipath calculations, a second direct access interface to the SWEG terrain data base will be required. The need for this second access to shared memory will depend upon the final architecture for the CNIL. This requirement will be reassessed as the CNIL design solidifies.

2.4.1.1 Scenario Update Rates. Simulation assets of SWEG may either be event driven or updated periodically. The update period for certain platform parameters such as positions (latitude, longitude, altitude) and attitudes (pitch, roll, yaw), is critical to the fidelity requirements of TESTS. Although further study may be required of this issue as TESTS research programs progress, a preliminary analysis indicates that approximately 1.0 degrees of angular motion, and 50.0 feet of relative translational motion can be tolerated per simulation update cycle. Assuming average aircraft angular rates of 30.0 degrees per second, or less, and average closing velocities of 1500 feet per second or less, a simulation update rate of 30 times per second should be adequate for TESTS. Discussions with NAVAIRTESTCEN personnel indicate that SWEG platform position and attitude data is commonly updated at 60 to 120 times per second during scenario execution. However, this is not fixed within SWEG. Each platform or player within SWEG can have different, user specified update rates. Combined with the capability to host multiple SWEGs and embedded SWEGs the capability should exist to meet all TESTS update requirements once all the complexities of SWEG are understood.

2.4.2 Role of Test & Evaluation in the NGIFF Specification

The cancellation of the MK XV program and its replacement with the NGIFF program provides the potential opportunity to alleviate several technical issues encountered during this effort. Under the MK XV program TESTS and the T&E activities were considered late in the program. As a result, several critical technical issues arose concerning the ability to accommodate almost any type of T&E within the program. With the NGIFF program, the opportunity exists to consider T&E requirements from the inception of the program and ensure that technical requirements to accomplish T&E are incorporated in the NGIFF specification. Hence, it is the conclusion of the UCF TESTS team that T&E should have an enhanced role in the development of the NGIFF specification.

2.4.2.1 Instrumentation Requirements for T&E. The TEMP for the MK XV program required a significant number of system parameters to be measured to evaluate the performance of the MK XV. A number of the TEMP parameters required access to data at various points within the MK XV internal circuitry. TESTS would require access to much of this same data to be complex. Hence, the T&E instrumentation requirements were very extensive. During the examination of the MK XV system specification, it was unclear whether the design of the MK XV would permit the required data access to conduct T&E. The modification of the MK XV to permit instrumentation for T&E could have been extensive and costly. The NGIFF specification should include T&E instrumentation requirements for DT&E and OT&E, not just black box bench tests, as an integral part of the specification. This will facilitate the effectiveness of the DT&E and OT&E process and reduce the risk associated with the development of TESTS. To achieve this goal the entire T&E plan, from component testing through OT&E, needs to addressed from program inception as part of the NGIFF requirements specification and system design process.

2.4.2.2 COMSEC/TRANSEC Requirements. One of the critical issues encountered during the TESTS feasibility assessment focused on the COMSEC and TRANSEC requirements for the MK XV. The MK XV performance is integrally linked to the classified encryption process. It is expected that the NGIFF will have a similar dependency. MK XV would not work without the KI box. A significant amount of discussion and investigation was devoted to the identification of ways to accommodate the COMSEC and TRANSEC aspects of the KI device within TESTS. The use of a maintenance key, as with the MK XII Mode 4, is not adequate for the MK XV or NGIFF applications.. Several alternate methods of incorporating the KI requirements were identified, but they all required some form of access to a validated set of encryption sequences. The COMSEC and TRANSEC data is highly classified and sensitive. Hence, the NSA does not make this data or details of the KI system performance readily available. While it is possible to simulate the KI operation, the validity of this simulation, and hence of the overall TESTS, cannot be established without an NSA approved and validated data base of encryption sequences. Without this data most T&E objectives cannot realistically be accomplished, nor can valid simulations be developed later for training devices. To eliminate this problem in the NGIFF, discussion with NSA should be initiated early in the program to determine an NSA approved method of incorporating the COMSEC and TRANSEC requirements in TESTS and other test or training devices. This should include the specification of an approved and validated encryption sequence data base that can be used for testing and training purposes. These items should be incorporated directly into the NGIFF systems specification to ensure their proper implementation.

2.4.2.3 TESTS as a Design Tool. While TESTS is intended to be used in DT&E, its development early in the NGIFF program could provide several derivative benefits during the design process. The various TESTS prototypes could be used during the design process to provide early evaluations of the NGIFF design, since the simulation could progress at a faster pace than the design and development practice. The utility of simulation to support the design process is well established. In addition, a simulation research test tool is being developed using BOSS to support the development of TESTS. This test tool is intended to aid in the development of simulation models and the conduct of research on propagation effects to be included in TESTS. However, this generic research simulation tool could easily be used to quickly evaluate design alternatives and the selection of parameter levels during the development of the NGIFF specification. Hence, this research tool could be used by the Navy to develop a more refined specification for the NGIFF which should reduce program risk. The ability to "simulate before you build" offered through the TESTS program could minimize some of the problems encountered during the MK XV program.

TESTS will also incorporate all of the features required in the test tool normally developed to support black box bench tests. Hence, TESTS could be applied to this portion of the T&E plan. This would provide a single unified test tool for the NGIFF and reduce risk as the program transitions between the various T&E phases.

2.4.3 Verification and Validation for TESTS

A strong requirement exists in the TESTS project to conduct a rigorous verification and validation (V&V) activity from the software unit level through the consolidated system level. As a consequence of this desire, the requirement traceability will be included in the approval process for the three configuration baselines, namely, functional, allocated and product.

Verification matches the new baseline against the requirements identified in the previous baseline to ensure that all requirements have been satisfied. Validation matches the new baseline against the original requirements for the system to ensure that the final product will meet the end user objectives. V&V relies on documentation reviews, contractor test monitoring, and independent testing to evaluate the products making up each of the baselines.

The testing is divided into two categories: (1) Development Test & Evaluation (DT&E), and (2) Operational Test & Evaluation (OT&E). DT&E is conducted to verify that design objectives have been met, that minimum risk has been attained and that functional performance of the final system has been properly estimated. Emphasis is on validation. OT&E, on the other hand, is conducted by the end user to verify that the final system meets the end user objectives and to determine impacts, if any, on end user operations when the system is installed. The emphasis here is on verification.

During the DT&E phase of TESTS the sequence of V&V tasks are applied to the required phases of DT&E:

(1) During the "concept exploration phase" alternative system concepts, technologies, and designs will be accomplished and validated.

(2) During the "demonstrated and validation phase" the preferred technical approach, including the identification of technical risks and feasible solutions will be determined.

(3) During the conduct of the "full scale development phase", (i.e., that the design meets its required specifications in all areas).

(4) After final system completion.

The method of implementation of the <u>testing portion</u> of these V&V tasks will be twofold. The first will entail the generation of unit "drivers" to stimulate the units under test and validate the functional accuracy of the outputs. The units will be sequentially put together with intermediate validation by known driver inputs until the entire system is assembled and similarly validated end-to-end.

The second method is to use actual flight data to V&V as many of the subunit modules as possible. The use of existing flight test data will be maximized during the formulation and execution of the V&V test plan. It is anticipated that requirements for additional parameter measurements of already planned flight tests will be needed to V&V intermediate stages of the simulation tool "TESTS." These requirements will be consolidated and identified early in the preparation of the functional specifications. Both methods will be planned and used to conduct a rigorous V&V program.

The second method (i.e. the use of actual flight data) for the implementation of the OT&E testing is recommended for the verification process. An outside organization should be considered to conduct an "Independent V&V" during this final phase (OT&E). A selected number of actual flight tests will be necessary to test the "envelope of performance" of TESTS and to verify as many of the TEMP objectives as possible.

3.0 TESTS APPROACH

3.1 RECOMMENDED TESTS CONCEPT

The TESTS feasibility assessment study evaluated four conceptual designs which vary in the degree of software/hardware allocation and the method for implementing signal generation and channel effects. Each of the four design approaches is summarized below.

Concept A - Sampled Data Interface

The most direct approach to TESTS signal generation and detection is the Sampled Data Interface concept. This approach consists of sampling or slicing a signal in time so as to represent a signal numerically by a sequence of numbers. This approach is a software intensive implementation of TESTS with hardware generation of the final RF signal.

Concept B - Pulse Level Interface

One manner in which computational and data transfer requirements may be alleviated within a TESTS RF simulation and stimulation tool is to apply pulse level decomposition to RF signals. The "Pulse Level Interface" concept approaches signal reception, processing and generation by applying pulse level decomposition and modeling to RF signals. This design approach shifts a moderate portion of the processing requirements to hardware in order to reduce the data rate requirements across the software/hardware interface.

Concept C - Message Level Interface

The Message Level Interface represents a logical step in the evolution of the TESTS concepts which alleviates the data transfer and computational requirements of the TESTS software by at least an order of magnitude over the Pulse Level Interface concept. It reallocates a larger portion of the processing to hardware. Under this design approach software assumes a "command and control" function whereby it generates messages and calculates environmental effects which are implemented through hardware.

Concept D - Hardware Intensive Design Concept

The last design concept is the Hardware Intensive Design Concept. Concept D represents the extreme in the evolution of the TESTS approach which employs a minimal amount of software signal processing. This approach assumes actual and complementary IFF equipment will be used to stimulate the SUT. Hence, the vast majority of the signal manipulation work in Concept D is done in TESTS hardware.

The analysis of the four concepts indicates that a hybrid approach combining the message level interface of Concept C with the signal and channel effects hardware in Concept D provides a flexible and effective design approach for TESTS.

Important aspects of the recommended approach to the TESTS hardware/software interface that are represented in Figure 3-1 are:

TESTS Receiver - Able to recognize each of the possible IFF signal types and modes, and to demodulate, decode, and despread the signal to determine message data content.

KI-( ) - Real or simulated encryption device that provides the COMSEC / TRANSEC sequences to the TESTS Receiver, TESTS Signal Generators, and Platform Under Test.

TESTS Signal Generators (XMIT) - Receives a complete message in binary (baseband) format from the TESTS host computer, and constructs the desired IFF message modulated at RF frequency for transmission over hardware channels to the Platform Under Test. The signal/message is split and distributed to separate primary and multipath channels for modification by the RF Signal Conditioner.

RF Signal Conditioner (G-P-D-F) - Special purpose hardware devices that can be used to dynamically introduce channel effects in the generated IFF signals. They contain programmable Gain (G), Phase (P), Time Delay (D), and Frequency Shift (F) devices that can be directly controlled from the TESTS host computer. Separately programmable paths will be provided to allow for at least one direct and one indirect signal path to simulate multipath effects at the receiver of the Platform Under Test.

Platform Under Test (PUT) - This represents the RF transmit and receive hardware lines of the actual IFF equipment on the Platform Under Test.

3.1.1 Block Descriptions

PLATFORM UNDER TEST:

<u>INTERROGATOR</u>

Functional Description:
SUT installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:
Interrogation requests from platform, KI-() COMSEC and TRANSEC coding information, RF reply waveforms.

Block Outputs:
RF interrogation waveforms, threat ID information.

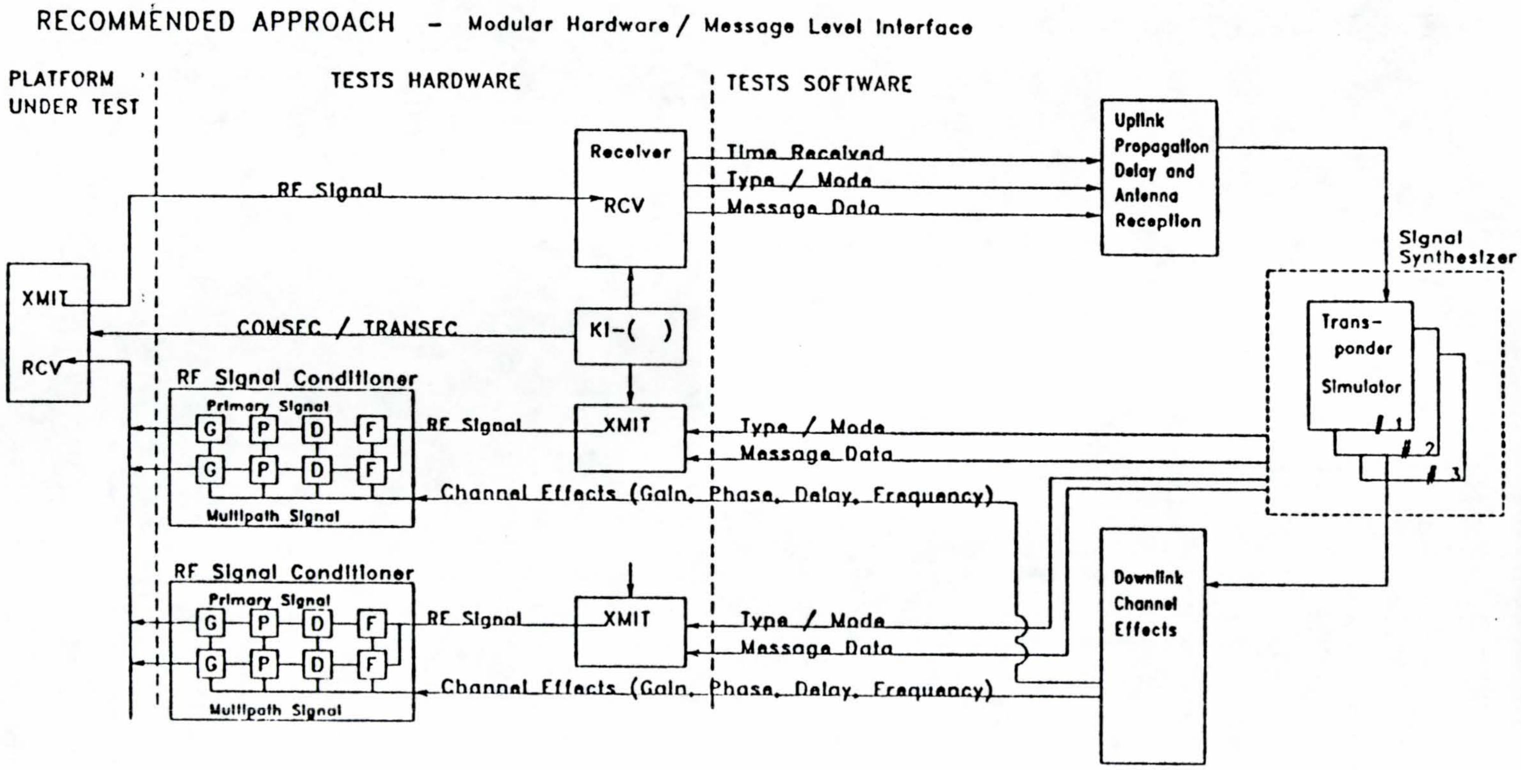


Figure 3-1 Recommended Approach - Modular Hardware / Message Level Interface

Internal Operations:
Uses COMSEC/TRANSEC coding information to generate interrogation waveforms in response to platform interrogation requests. Uses COMSEC/TRANSEC coding information to interpret RF reply waveforms.

TRANSPONDER

Functional Description:
System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:
RF Interrogation WAVEFORMS, KI-()
COMSEC and TRANSEC information.

Block Outputs:
RF reply waveforms.

Internal Operations:
Uses COMSEC/TRANSEC coding information to interpret interrogation waveforms and generate, when appropriate, reply waveforms.

TESTS HARDWARE:

SIGNAL RECEIVER

Functional Description:
Detects RF IFF signals from SUT, converting them to a message level data format.

Block Inputs:
SUT IFF system output waveforms; COMSEC/TRANSEC information.

Block Outputs:
Message level data format RF signal description.

Internal Operations:
Message level signal recognition and demodulation including despreading, decoding and/or decryption.

SIGNAL TRANSMITTER

Functional Description:
Converts software generated message level data format signals into RF SUT stimulus signals.

Block Inputs:
Message level data format RF signal descriptions; COMSEC/TRANSEC information.

Block Outputs:
RF SUT stimulus signals.

Internal Operations:
Message level modulation including spreading, encoding and/or encryption.

KI-()

Functional Description:
Crypto unit which interacts with MK XV or Navy Advanced IFF Subsystem to provide COMSEC/TRANSEC information to IFF Subsystem and TESTS host processor.

Block Inputs:
Time of day information and key codes.

Block Outputs:
COMSEC/TRANSEC codes via shielded cable.

Internal Operations:
Actual internal operation is classified and may be replaced in some test cases with an unclassified substitute.

RF SIGNAL CONDITIONER

Functional Descriptions:
Implementation of channel effects on RF signals.

Block Inputs:
Control signals originating in software.

Block Outputs:
Perturbations on RF signals.

Internal Operations:
Programmable time delay would respond to predetermined control signals with predetermined amounts of uniform group delay. Programmable phase and gain blocks would similarly apply variable levels of carrier phase and signal attenuation.

TESTS SOFTWARE:

UPLINK PROPAGATION DELAY AND ANTENNA RECEPTION

Functional Description:
Computes propagation delay to message level data format SUT RF signal descriptions and passes data if it was received in the antenna's reception lobe.

Block Inputs:
Message level data format descriptions of SUT RF signals.

Block Outputs:
Message level data format signal descriptions modified for propagation delay.

Internal Operations:
Addition of propagation delay via message level data format descriptions computed for direct and reflected signals. Rejects data if it was not received in the antenna's reception lobe.

<u>TRANSPONDER SIMULATOR</u>

Functional Description:
Invokes TESTS interrogations or replies appropriate to the test function and time dependent scenario conditions.

Block Inputs:
IFF message types, modes and content.

Block Outputs:
New IFF message types, modes and content.

Internal Operations:
Follows test scenario to simulate individual IFF platforms.

<u>DOWNLINK CHANNEL EFFECTS</u>

Functional Description:
Computes channel effects to message level data format.

Block Inputs:
Simulation scenario environment information.

Block Outputs:
Control signals for programmable time delay, phase and gain blocks.

Internal Operations:
Addition of channel effects via message level data format descriptions.

3.1.2 Supporting Discussion

In the Message Level Interface approach the entire IFF message is represented in digital data format. The TESTS Hardware consists of a receiver and a bank of signal transmitters. The Recommended Concept receiver is designed to detect, demodulate, decode and despread interrogations from the SUT. The message contained in the interrogation is then passed on to TESTS software along with the time received and the type of interrogation employed. TESTS signal synthesizer software components can then work directly with digital baseband data, in order to formulate appropriate responses. The signal transmitters in TESTS hardware may be invoked by TESTS software to send given replies to the SUT under given modulation types or modes. The Recommended Concept TESTS software components accomplish scenario simulations by tracking platform positions and computing uplink and downlink channel effects. These effects are introduced via a software driven hardware interface subsystem which has been labeled an "RF Signal conditioner" This TESTS hardware subsystem is comprised of programmable TESTS hardware gain blocks, phase blocks, frequency changers and time delay lines.

This configuration differs from that of Design Concept D in that the signal generator devices (XMIT) are driven from the TESTS software components and each may be used to generate multiple transponder or interrogator signals via time division multiplexing, under control of the TESTS host computer. A number of separate signal generators may be easily added to increase the reply rate or Interrogation rate capacity of the TESTS system. The programmable gain, phase, time delay, and frequency distortion devices are special purpose hardware devices that can be built separately, and used in a modular fashion to introduce channel effects in the generated signals. This separates the hardware functions, and allows for easier specification, design, testing and calibration of the equipment. It also provides for a more low cost growth path to achieve the final TESTS capacity requirements, and it allows for greater flexibility in utilization of TESTS equipment. For example, the channel effects boxes of this approach could also be used to connect an actual IFF transponder and interrogator pair, to approximate the configuration shown in Design Concept D. As shown in Figure 3-1, each channel effects box would contain at least two sets of separately programmable signal distortion devices, in order to simulate at least one indirect bounce path for multipath effects. If more than one bounce path is required for certain multipath conditions, multiple boxes could be used in parallel with the same RF Signal input to achieve this effect.

This hybrid combination of Concepts C and D provides a flexible and effective design approach for TESTS. Furthermore, while requiring a systematic design and research effort, this approach is the opinion of the IST/UCF team that it is both cost-effective and technologically achievable.

3.2 TESTS PROTOTYPE BUILD PLAN

In order to provide a low risk, high confidence, and low cost approach to the design, purchase, fabrication, and integration of the hardware and software components of the TESTS system, an evolving Prototype Build Plan will be adopted as shown in Figure 3-2. This plan shows a number of incremental builds which provide increasing capability and diversity in the number of platforms and signals to be generated, and simultaneously, increasing fidelity in the environmental and channel propagation effects to be simulated by TESTS. This evolutionary approach will allow early closed loop testing and validation of the TESTS system with existing IFF systems such as the MK XII, and provide a low risk transition to more advanced IFF systems utilizing spread spectrum signals. It will also provide scheduling milestones for the completion and integration of faculty research projects regarding the various channel effects, with the corresponding design requirements for TESTS software components and signal generation hardware.

Figure 3-2 was derived while the TESTS was responding to the MK XV program. As the new Navy unique advanced IFF program progresses, the prototype build plan will need to be updated. It is expected that other Navy aircraft platforms, e.g., F-14 will replace the Air Force F-15 in the matrix. The order of platforms in the build matrix may also change as the Navy formulates its test plan. Other aspects of the build plan may initally remain unchanged with updates incorporated as the Navy unique objectives unfold. It is likely that both the missile and ship models will remain in the build plan to accommodate aircraft testing in all operational settings, e.g., a complete test of an airborne transponder includes its ability to receive and correctly reply to a missile interrogation such as the Hawk's. The original build plan incorporates the worst case TESTS development scenario, hence this initial plan will be retained until further definition of the Navy unique IFF test plan becomes available.

3.3 ACETEF INTEGRATION AND INTERFACE

The ACETEF provides a controlled environment for integrated testing of aircraft avionics systems at the NAVAIRTESTCEN. ACETEF provides a suite of laboratories and facilities that can interact to provide a variety of electromagnetic test environments and stimulations for actual avionics systems mounted on an aircraft and radiated in an anechoic chamber. An adjacent shielded hangar provides additional space for hard wired testing of several aircraft. Presently there are several operational elements of ACETEF, such as the Aircrew Systems Evaluation Facility (ASEF), the Electronic Warfare Integrated Systems Test Laboratory, (EWISTL) the Electromagnetic Environmental Generation System (EMEGS), and the Tactical Avionics and Software Test and Evaluation Facility (TASTEF). Other planned facilities include the Communications, Navigation, and Identification Laboratory (CNIL), the Offensive

Sensors Laboratory (OSL), the Electromagnetics Environment Effects Test Laboratory (E^3TL), and others. TESTS will integrate into the expanding capabilities of ACETEF, initially to provide Development Testing of the MK XII / MK XV IFF system, and eventually to provide full Operational Testing of IFF systems as part of the CNIL. It is anticipated that TESTS will be employed in at least four different configurations:

TESTS – Prototype Build Plan – page 1

	PLATFORM							SIGNALS				Dynamics			
Prototype	F-18 (XP)	F-15 (IR)	F-15 (XP)	Hawk (IR)	Ship (IR)	Radar Mode (X-IR)	Radar Mode (S-IR)	Mk XII (Clear)	Mk XII (Mode 4)	Mk XV	Mode S	Stationary	Moving	SWEG	
1.0	X							X				X			
1.1	X	X						X				X	X		
1.2	X	X						X	X			X	X		
2.0	X							X	X	X		X	X		
2.1	X	X						X	X	X		X	X		
2.2	X	X	X					X	X	X		X	X	X	
3.0	X	X	X	X	X			X	X	X		X	X	X	
3.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

Figure 3-2 TESTS Prototype Build Plan (1 of 2)

TESTS – Prototype Build Plan – page 2

Prototype	Emitters		Terrain Data			Multipath		Antenna			Propogation				
	Single	Multiple	4/3 Rad Earth	DMA Topography	Roughness	Single Reflection	Stochastic	Free Space	Platform Masking	Coupling	Standard Atmos.	Weather	Dust / Clouds	Ducting	
1.0	X		X			X		X			X				
1.1	X		X			X		X			X				
1.2	X	X	X			X		X			X	X			
2.0	X	X	X			X		X	X		X	X			
2.1	X	X	X			X		X	X		X	X	X		
2.2	X	X	X	X		X		X	X		X	X	X		
3.0	X	X	X	X	X	X	X	X	X	X	X	X	X		
3.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

Figure 3-2 TESTS Prototype Build Plan (2 of 2)

1. as a stand alone benign test tool to provide IFF testing on aircraft in the shielded hangar,

2. as a stand alone test tool integrated with additional equipment such as the Tactical Agile Signal Simulator (TASS), used to provide an ECM/jamming environment,

3. integrated in CNIL with CNIL operating independently of ACETEF, or

4. in a fully integrated ACETEF testing environment utilizing several assets at once to test aircraft systems in the anechoic chamber.

3.3.1 SWEG Interface

The primary interface of TESTS to the other components of ACETEF required during testing will be provided by the SWEG. An outgrowth of the SUPPRESSOR simulation program, SWEG has been updated to control and coordinate tactical engagement simulations in ACETEF, and provides a rich library of platform and emitter models. SWEG provides a standard format for the shared memory interface between the various components of ACETEF, and defines the protocol for interactions between components. The software components of TESTS will interface to the SWEG shared memory for required scenario simulation data, such as platform positions, attitudes, velocities, terrain elevation data, antenna pattern directional attenuations, antenna scan rates, etc. TESTS will utilize or upgrade existing ACETEF simulation models whenever possible, and will conform to the ACETEF established conventions for scenario preparation, initialization, execution, shutdown, and post processing phases of operation. Note that TESTS will utilize some subset of SWEG capabilities to provide scenario preparation and execution, even when operating in a stand alone configuration in the shielded hangar. It is anticipated that all interactions between TESTS software components, and other components of ACETEF, will take place via the SWEG shared memory interface.

While TESTS can operate in a stand alone configuration or integrated through CNIL to ACETEF, SWEG will always be required. In the stand alone configuration SWEG will need to be hosted at a workstation level, such as a VAXstation. When integrated with CNIL/ACETEF, TESTS will receive SWEG inputs through the appropriate level of shared memory. In the CNIL/ACETEF integrated configuration TESTS may require two interfaces to the shared memory. In order to meet real time processing requirements for multipath calculations, a second direct access interface to the SWEG terrain data base will be required. The need for this second access to shared memory will depend upon the final architecture for the CNIL. This requirement will be reassessed as the CNIL design solidifies.

The SWEG terrain data base utilizes standard DMA data. The resolution of the data base is determined by available memory. The SWEG terrain data base can accept the finest resolution of DMA data available. While DMA data is not of infinite resolution, it is sufficient to achieve a moderately high level of fidelity. It should be noted that almost any level of terrain resolution is representative of actual terrain somewhere. Given the resolution of terrain data available to SWEG, the capability exists to provide an environment representative of most terrain. Hence, it does not appear that the SWEG terrain data base resolution will impose any severe limitation on the development or utility of TESTS.

The most critical technical terrain data base issue is the real time calculation of platform inter-visibility. This is critical for low altitude platforms, especially when a large number of platforms are present and terrain elevations are changing rapidly. Under these conditions, terrain masking can be changing very rapidly. This is an area of the simulation that will require careful study. A number of efforts are ongoing to deal with this problem in other projects, some underway at IST. These current efforts are examining a variety of approaches to resolving the problem. Some approaches involve brute force computing power, others use innovative techniques such as precomputed inter-visibility surfaces and position predictive algorithms. We are examining various approaches to determine the most effective to TESTS. While this is a difficult problem, solutions exist. Additionally, it should be recognized that the percentage of the total scenarios in which this is a factor is relatively low. Hence, the potential impact on the overall utility of TESTS may not be large.

3.3.2 Scenario Update Rates

Simulation assets of SWEG may either be event driven or updated periodically. The update period for certain platform parameters such as positions (latitude, longitude, altitude) and attitudes (pitch, roll, yaw), is critical to the fidelity requirements of TESTS. Although further study may be required of this issue as TESTS research programs progress, a preliminary analysis indicates that approximately 1.0 degrees of angular motion, and 50.0 feet of relative translational motion can be tolerated per simulation update cycle. Assuming average aircraft angular rates of 30.0 degrees per second, or less, and average closing velocities of 1500 feet per second or less, a simulation update rate of 30 times per second should be adequate for TESTS. Discussions with NAVAIRTESTCEN personnel indicate that SWEG platform position and attitude data is commonly updated at 60 to 120 times per second during scenario execution.

3.4 SOFTWARE DEVELOPMENT APPROACH

The TESTS project will utilize a tailored MIL-STD-2167A software development approach. A tailored approach to DoD software development standards is proposed to accommodate the prototyping approach to the TESTS development, accommodate the research aspects of TESTS and maintain the cost effectiveness of the TESTS concept. Figure 3-3 provides an overview of the real time system development process which will be implemented in TESTS. It depicts major design, development and test activities, major project milestones.

The term prototype as used herein refers to an instance of a software version that does not exhibit all properties of the final system as defined in DoD-HDBK-287. It is an intermediate stage to the development of the final product. TESTS will be developed following an evolving prototype approach. This approach has the advantage of providing continual feedback on the progress and operation of TESTS. This approach has been successfully used in a number of major DoD programs. While not the standard MIL-STD-2167A approach to system development, the evolving prototype approach is compatible with and can be implemented in compliance with the requirements of MIL-STD-2167A. Figure 3-4 depicts the flow of an evolving prototyping approach within MIL-STD-2167A.

While the TESTS tailored MIL-STD-2167A approach will greatly reduce the project documentation requirements, the UCF TESTS project team recognizes the need for comprehensive and properly developed documentation. The SDP provides for documentation which meets the intent of MIL-STD-2167A. The documentation will provide complete design details, audit trails, manuals, test reports, etc. The goal is to ensure that the documentation will support design reviews, TESTS operation and TESTS software maintenance. Figure 3-5 shows a <u>simplified</u> flow of the documentation development for TESTS.

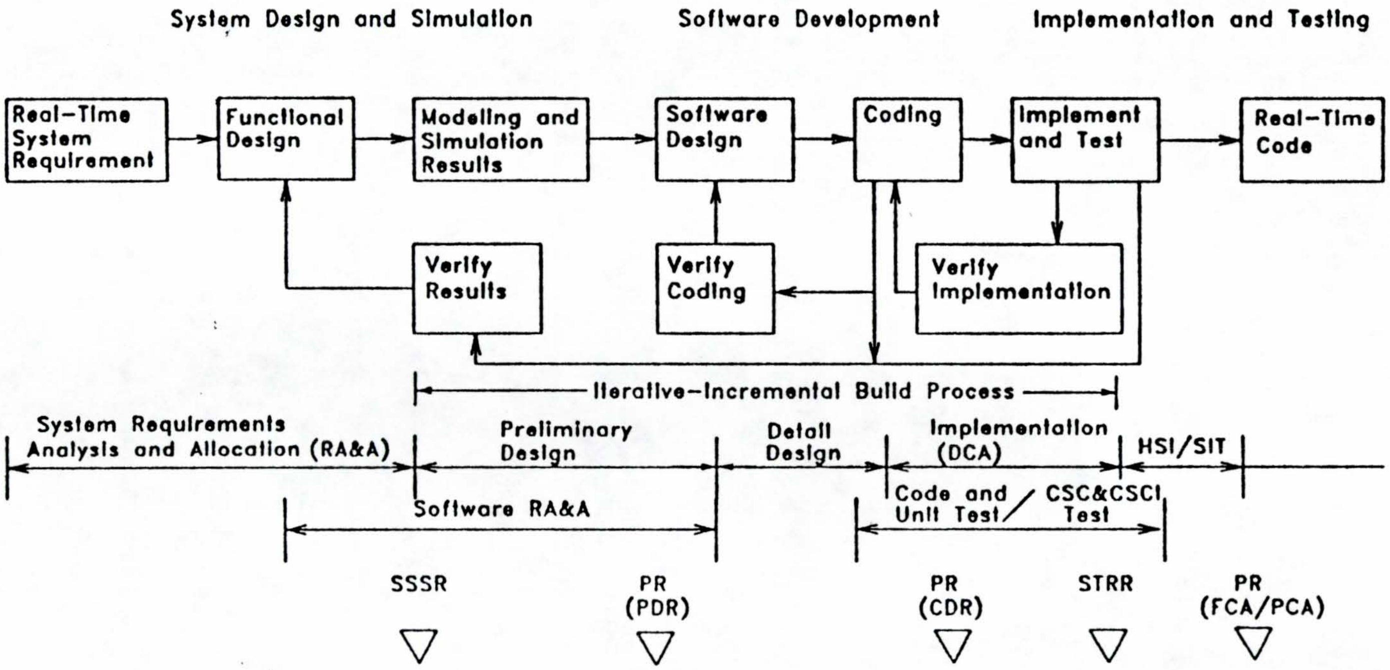
3.5 TESTS - CONCLUSION

There are four major functional blocks within the overall TESTS architecture as shown in Figure 3-6 . These major functional blocks within TESTS, which include supporting interface structures, consist of the TESTS simulator component, the TESTS stimulation component, the scenario control component and the environmental component. The first two components comprise the core functionality of TESTS. The later two components are external capabilities required for TESTS to be fully functional.

Simulator Component

In the signal generation operation, the TESTS simulator component generates IFF messages, calculates propagation effects, etc., in software and formats the simulation commands to the stimulation component. In the receiving operation, the simulator component decodes the received signal and passes it to the data capture facility.

REAL-TIME SYSTEM DEVELOPMENT PROCESS



Notes on Tailoring:

1. 2167A and 1521B call out 9 major reviews as minimum plus potentially separate HW-SW PDRs/CDRs: Schedule above shows 5 reviews but assumes the PDR, CDR, & FCA/PCA could be replaced by a Progress Review (PR)
2. 2167A calls out 17 Data Items and 490A implies A, B and C specs. A potential plan for SW Development would be to combine the SSS (Aspec) and the PIDS/CIDS (B/C) and the SSDD into the Functional Description (FD), DI-E-30104B, with a contractor defined RTM.

Figure 3-3 Overview of Real Time System Development Process

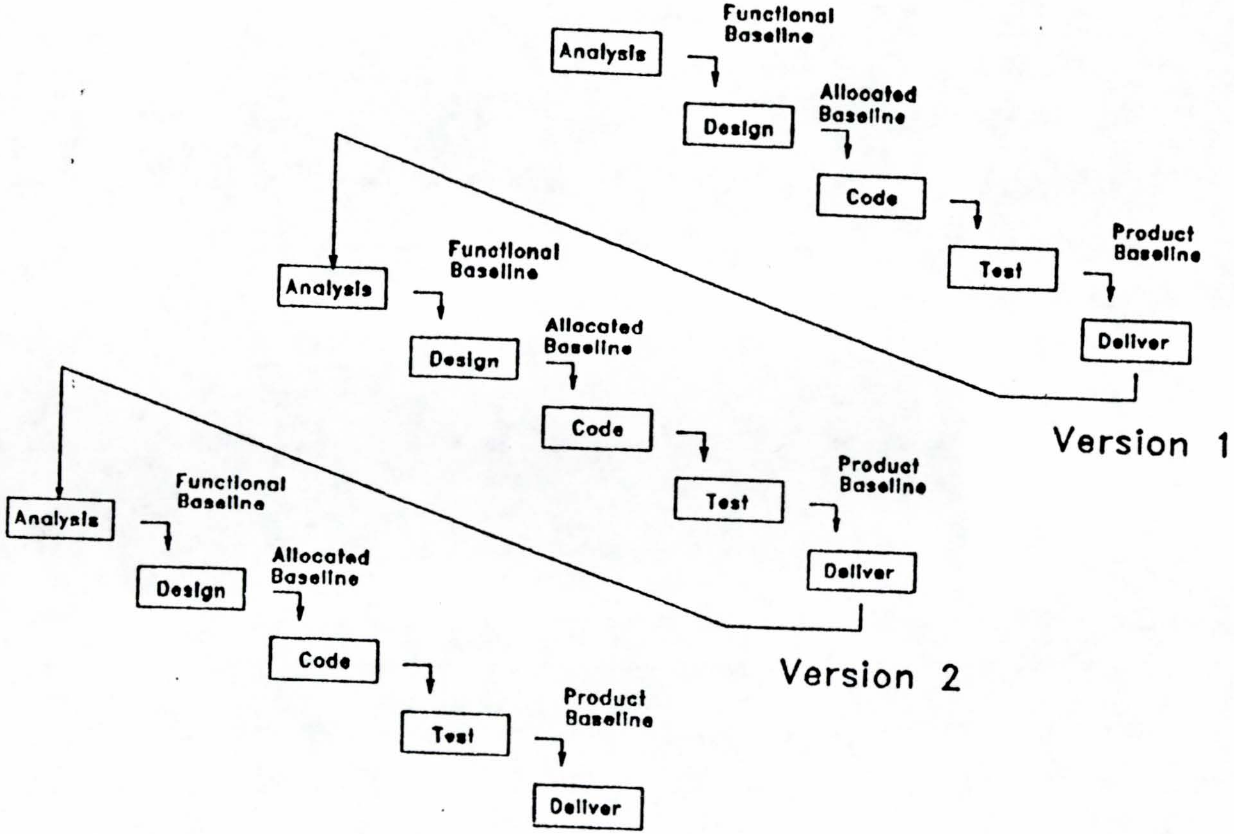


Figure 3-4 Prototyping in a MIL-STD-2167 Development Environment

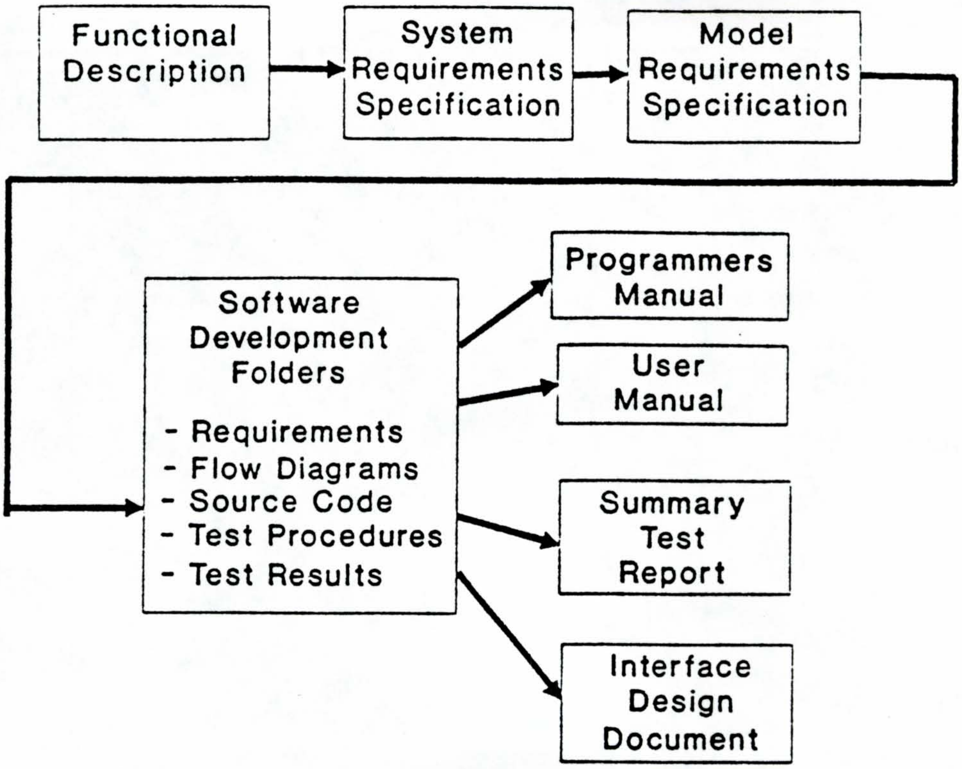


Figure 3-5 Simplified Evolution of Software Documentation

Stimulation Component
The stimulation component is the hardware RF generator portion of TESTS. It includes both the signal generation hardware and the signal distortion, i.e., channel effects, hardware. This component translates the message level simulation command into the appropriate signal signature(s), both data and characteristics, required to stimulate the SUT. On the receiving side, it demodulates the SUT signal and transforms the received signal into a format interpretable by the simulator module.

Scenario Control Component
The primary scenario control component for TESTS is SWEG. SWEG provides all of the operational information concerning platforms, and environmental data and terrain data required for multipath and other propagation effects determinations. This component also initializes the appropriate test conditions and provides the interface to other facilities, e.g., CNIL, ACETEF. SWEG will be augmented by a TESTS specific scenario control subcomponent if it is determined that all parameters required for TESTS can not be obtained from SWEG.

Environmental Component

The environmental component provides the jammer/ECM environment for TESTS. This component will be provided by external resources. TESTS will provide the appropriate interface to integrate this capability. Depending upon the TESTS configuration, this capability may be provided by ACETEF through EWISTL or other off-the-shelf hardware.

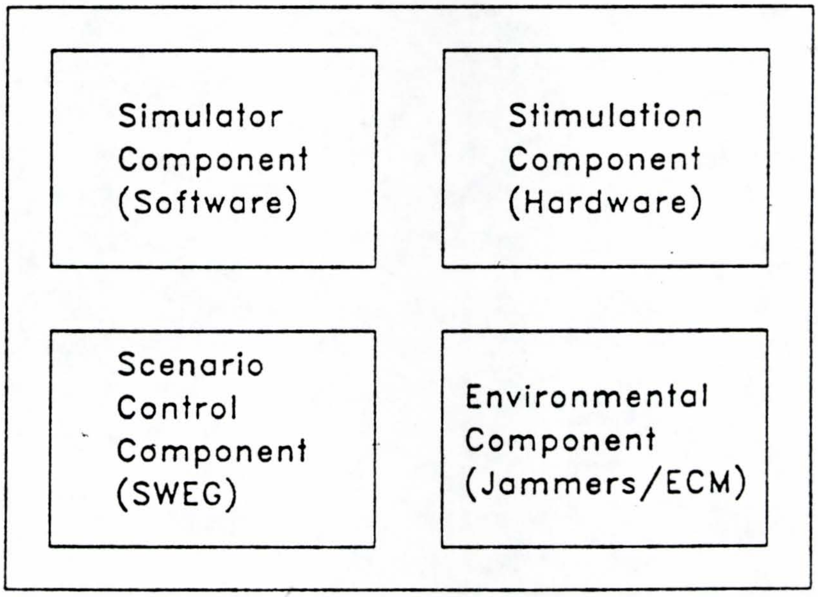


Figure 3-6 TESTS: System Simulator Tool

4.0 PHASE I RESEARCH

The following sections summarize the research conducted during the TESTS Phase I effort. Research focused in four areas. Three areas, electromagentics, communications and signal generation were the responsibility of researchers in the Department of Electrical Engineering. The fourth area of research involved design tradeoff studies conducted by IST to support the development of the TESTS conceptual design.

4.1 ELECTROMAGNETIC RESEARCH FINDINGS

The following section summarizes the research findings of the electromagnetics group comprised of Dr. Christodoulou and Dr. Wahid. These findings focus on three primary topics; near fields and antenna patterns, multipath effects and propagation effects.

4.1.1 Near Fields and Antenna Patterns

In order to have any kind of relation with real world performance, the antenna characteristics have to be incorporated on the stimulation signal. The near field and far field patterns can be incorporated in terms of power, gain, directivity, phase, and polarization. The stimulated signal will depend on the efficiency and gain of the transmitting and receiving antennas.

After an extensive investigation we found that the best available models for evaluating the effects of near fields and all platform effects, as well as, far-field radiation patterns are the following:

NEC-Basic Scattering Code
High Frequency
Based on the Uniform Theory of Diffraction
It can handle various platform Geometries
We have acquired this model and we are currently evaluating it.

New Air
High Frequency
Based on the Geometrical Theory of Diffraction
It can handle aircraft platforms (If antenna is placed on fuselage)

INAC-3
Low Frequencies
Based on the method of momemts
It can handle ship and aircraft geometries

GEMAGS
Most Frequencies of Interest
Hybrid method (GTD and Method of Moments)
Good for all geometries
We have ordered this model and we expect it to be the most promising.

STRIPES
Most Frequncies of Interest
Transmission Line Method -It requires a mesh generation (could be a frequency limitation)
It can be applied to various platform geometries.
We are currently evaluating a demo package .

4.1.1.1 Three-Dimensional Patterns. Currently, flight measurements at NATC and other facilities can yield complete azimuthal plane patterns and partial elevation patterns.This limitation can be very critical in a real life situation since interrogations and responses can be transmitted or received in any direction and angle. The capability of having a three-dimensional radiation pattern will greatly enhance the confidence and reliability level of a communication link between two vehicles. Also, having a model that can predict, accurately, three dimensional patterns will save a lot of time and money by reducing the number of flight measurements required.

The models described in the previous section will also lead in the generation of three dimensional patterns.

4.1.1.2 Coupling Among Antennas. The degree of coupling between two or more antenna depends on the type of antenna under test, their location on the platform, their proximity to various conducting objects, their frequency of operation and the polarization of the transmitted and received waves.

This problem could be quite complex and it will require further research once the information on the antennas and their arrangement are known.

We propose to include this option into the model that will be developed to handle the 3-D radiation patterns and platform effects, since a change in the coupling changes the patterns as well. Coupling is important because it can change the gain of the transmitting and receiving antennas. Without this information the system cannot accuaretely be calibrated.

Coupling is directly related to the near field effects of the antennas. An accurate near field pattern without allowing for any coupling could first be obtained using standard antenna theory. This could also be obtained experimentally, or depending on the complexity of the pattern, it could be extracted from a knowledge of far field characteristics. The coupling would be introduced as a second step and its effects on the antenna near field characteristics would be studied.

GEMACS can handle coupling among antennas as they are placed on various platforms.

4.1.1.3 Testing and Verification.

Far-field and near field patterns.
Will be verified by comparing our data against published theoretical and experimental data, as well as, data provided by NATC.

3-D plots
Can be verified by comparing our results with available in flight measurements from NATC. Some additional in-flight measurements may be required for further verification of this part.

Coupling
It can be verified , partially, by using exprerimental techniques, such as, lab measurements and in-flight measurements. Prior to the verification of this part the platform effects and 3-D patterns should be verified.

All the above mentioned effects should be incorporated on the stimulation signal to produce a real life IFF scenario.

4.1.2 Multipath Effects

We have divided this problem can be divided into the following three categories :

Sea Surface Reflection
It is important that we can predict the effects of multipath propagation and their probability of occurrence due to sea reflection on the received signals. These effects will introduce signal fading, phase delay and depolarization. The point of reflection between a transmitter and a receiver should also be determined given the distance of the transmitter and receiver and their heigth above the sea. Reflection from random sea surfaces (other than calm state) should also be determined.

Near Land Effects
Predict the multipath effects due to the proximity of land to a sea body. In this case, not only reflections but paths emanating from diffraction phenomena due to the surrounding terrain near a sea body should also be included. The amount of energy and diffracted depends on the geometry of the land near the sea body and its electrical properties.

Complex-Irregular Terrain
Find the multipath effects (and the probability of their occurence) on the transmitted signal due to various land terrains. Land terrains are characterized by irregular distributions of obstacles, such as, hills, buildings, trees, etc. A model based on statistical methods, should be developed to predict the probability of occurrence, the signal attenuation and phase delay of a transmitted pulsed signal.

4.1.2.1 Available Models. The presence of the earth (hills, buildings, sea, lakes, etc.) near a radiating antenna affects the radiation mechanism by introducing the following phenomena

a) Reflection or Scattering of energy directed towards the earth (hills, sea, etc). The amount of energy reflected and its direction depends on the geometry and electromagnetic properties of the ground, sea, etc.

b) Diffraction Phenomena} due to the introduction of finite size objects in the path of the incident field.

c) Refraction Effects} due to atmospheric inhomogenuities which lead to ducting, ray bending, etc.

4.1.2.2 Sea Surface Reflection. For this problem we intend to use Balanis' model, which covers:

1. receiver and transmitter antenna heights,
2. path lenth and divergence,
3. receiver and transmitter antenna beamwidths and polarization states,
4. frequency,
5. ground-to-air cases,
6. air-to-ground cases, and
7. Air-to-air cases.

This formulation is well documented and valid provided the sea surface is smooth. It does not consider any other sea states due to various wind conditions.

For a non-calm sea situation this model has to be modified to take into consideration the random nature of waves. This complicates the formulation because depending on the height of the waves there may be more than one reflected paths directed towards the receiving antenna. The problem here is to determinate an average reflection coefficient and the probability that a ray of significant magnitude will be reflected towards the receiver.

4.1.2.3 Near Land and Irregular Terrain. Normally, irregular multipath propagation exist in hilly terrain, but it can also be found in any populated areas where obstacles, such as, buildings, trees, etc. are present. System degradation due to multipath effects depends on the particular system used. In this project, we are interested, primarily, in pulse communication systems. In particular, the delays of the reflected or diffracted pulses pose a potential problem, depending on the pulse width and the amplitude of the reflected (diffracted) pulses and the distance of separation between the receiver and transmitter.

Usually, the amplitude of the reflected pulse has to fall within a certain range above and below the amplitude of the direct-path signal before system degradation occurs. If the reflected signal is substantially smaller than the direct-path signal it is suppressed. On the other hand, if the reflected signal is larger then is locked onto instead of the direct-path signal. For this project, it is important that we develop a model that predicts the frequency of occurrence of multipath propagation and determine the delay and change in amplitude.

Over the years, various models have been developed for different terrains, heights above these terrains, frequency of operation, range, and pulsewidth of transmitted signals. The two models that we are proposing to start with are explained herein:

4.1.2.3.1 **Model 1-Multipath for Pulse signals.** In this model, the probability of occurrence of multipath propagation of pulse signals over irregular terrain at VHF and UHF are determined. This model considers :

1. gain of transmitting antenna,

2. gain of receiving antenna,

3. directive gain of antenna,

4. transmitter-receiver distance of separation,

5. effective aperture of antenna,

6. antenna efficiency,

7. height of transmitting antenna, and

8. height of receiving antenna.

For ``Irregular'' terrain, Egli has derived a statistically derived expression for the median received power at frequencies above 40 MHz. We plan to use this model for our frequency range of interest.

4.1.2.3.2 **ECAC Model.** This model was developed by the Electromagnetic Compatibility Analysis Center in Annapolis and it can handle the line-of-sight, Diffraction, and Tropospheric modes of propagation over an irregular terrain. Basically, we propose to use the Terrain Integrated Rough Earth Model (TIREM). This code covers :

1. most multipath effects between 20 MHz and 20 GHz,

2. distance and elevation profiles,

3. geographic coordinates (Latitude ad Longitude) of the transmitter and receiver,

4. environmental parameters of the terrain (permittivity, conductivity, etc.),

5. antenna heights, their frequency, and polarization,

6. antenna gains and transmitter power,

7. topographic profiles between the transmitter and the receiver. (Terrain topography can be obtained from the Defense Mapping Agency DMA for many locations or the user can input any terrain profile of his own.), and

8. degree of reliability of the propagation between a transmitter and a receiver.

This model, however, does not consider pulse signals and their dispersion through the atmosphere. It is also restricted to a number of specific types of antennas. That means that an antenna radiation pattern that include all platform effects should be entered in this code to simulate real life signals.

A number of different analyses were completed using the ECAC program. Figure 4-1 illustrates an example of transmission over complex terrain, and over a calm sea state for various atmospheric humidity values. Table 4-1 (Frames 1-15) provide an example of the input files for the ECAC software package. In this example the elevations of the transmitting and receiving antennas were varied over a complex terrain to study the losses in the propagation link. Table 4-2 (Frames 1-23) provide the print outs of the ECAC TIREM results for the study example. These results specify what mode of propagation should be chosen, as well, as, the losses incurred along the path. Figures 4-2 and 4-2 summarize the findings for propagation loss over sea and complex terrain. The results are plotted for frequency increments between 1 GHz and 12 GHz.

4.1.2.4 References

D.E. Kerr, Propagation of Short Radio Waves, MIT Radiation Laboratory Series, McGraw-Hill Book Co., 1951, Vol. 13, pp. 396-444.

C.A. Balanis, R. Hartenstein, and D. Decarlo, "Multipath Interference for In-Flight Antenna Measurements," IEEE Trans. on Antennas and Propag., vol. AP-32, No. 1, January 1984, page 100.

C.A. Balanis, Antenna Theory- Analysis and Design, Harper and Row, 1982.

H.R. Reed and C.M. Russell, Ultra High Frequency Propagation, Chapman Hall Ltd., 1965.

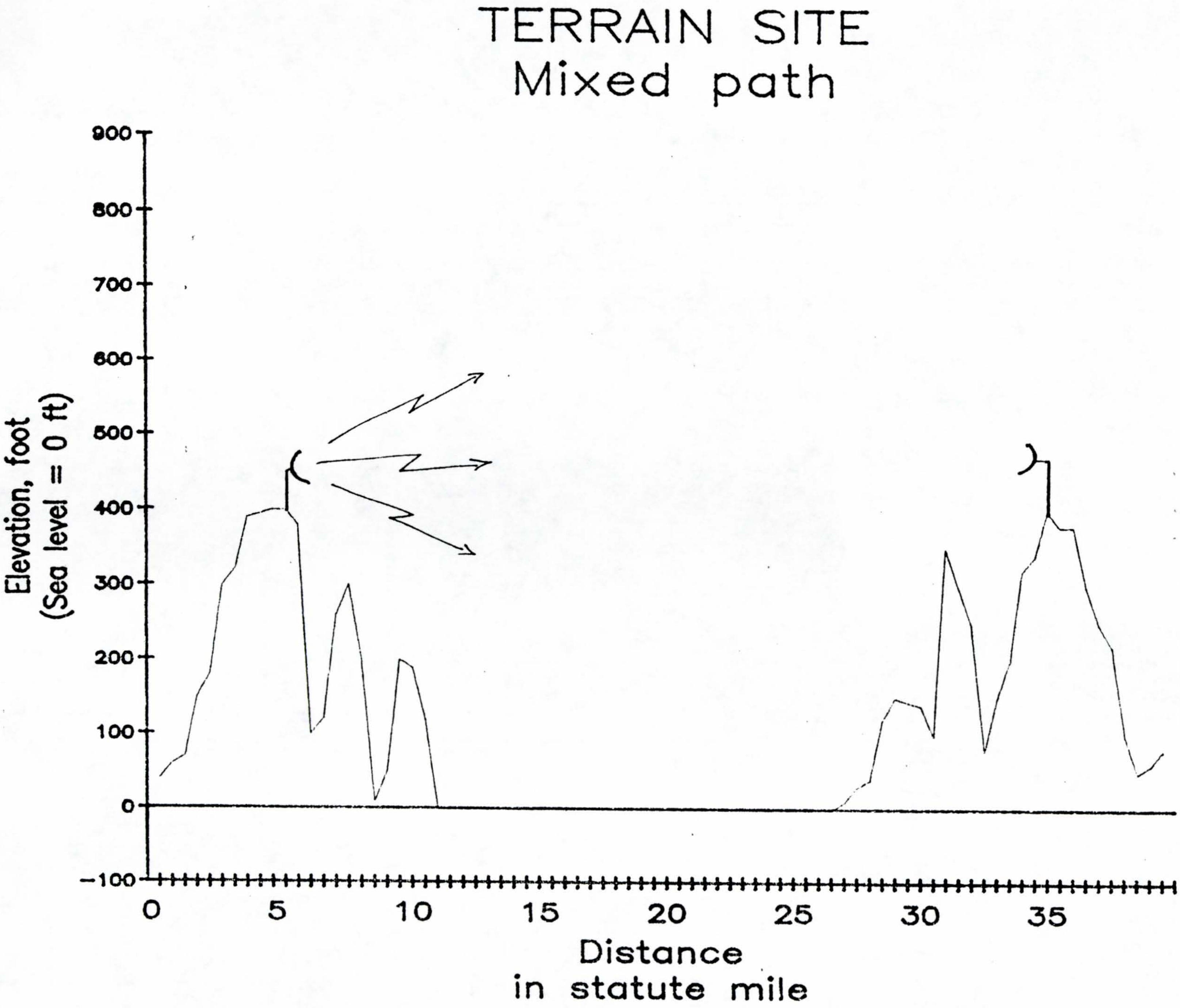


Figure 4-1. Illustration of Mixed Path Terrain Site.

TABLE 4-1

EXAMPLE OF ECAC INPUT FILES

```
*****************************************
*                                       *
*  TERRAIN INTEGRATED ROUGH-EARTH MODEL *
*                                       *
*               (TIREM)                 *
*                                       *
*****************************************

   THE TERRAIN INTEGRATED ROUGH-EARTH MODEL (TIREM) EXAMINES THE
TERRAIN PROFILE BETWEEN TRANSMITTER AND RECEIVER AND CALCULATES
THE PROPAGATION LOSS BY CHOOSING THE PREDICTION ALGORITHM THAT
BEST REPRESENTS THE ACTUAL PROPAGATION MODE.    LINE-OF-SIGHT,
DIFFRACTION, AND TROPOSPHERIC SCATTER MODES ARE SELECTED FOR
EITHER SMOOTH OR IRREGULAR PROFILES, AS APPROPRIATE.   TIREM IS
APPLICABLE FROM 20 MHz TO 20 GHz.
                                                  TRANSMIT TO CONTINUE




                  -------------------
                  TRANSMITTER INPUTS
                  -------------------

   TRANSMITTER ID:                              [ TRANSMIT]

   TRANSMITTER ANTENNA STRUCTURAL HEIGHT:       [ 50     ]   ( FT)

   TRANSMITTER ANTENNA POLARIZATION:            [ V]  V - VERTICAL
                                                      H - HORIZONTAL

   TRANSMITTER FREQUENCY:                       [ 1000    ]  ( MHZ)

   TRANSMITTER POWER:                           [ 25      ]  (  W )

   TRANSMITTER ANTENNA GAIN:                    [ 20  ]      (dBi)

   TRANSMITTER ANTENNA MAXIMUM DIMENSION:       [ 10  ]      ( FT)
```

TABLE 4-1 (Con't)

EXAMPLE OF ECAC INPUT FILES

```
                        ---------------
                        RECEIVER INPUTS
                        ---------------

     RECEIVER ID:                                [ RECEIVER]

     RECEIVER ANTENNA STRUCTURAL HEIGHT:         [ 50     ]    ( FT)

     RECEIVER ANTENNA GAIN:                      [ 20   ]      (dBi)

     RECEIVER ANTENNA MAXIMUM DIMENSION:         [ 10    ]     ( FT)




                     ---------------------
                     TROPOSCATTER ANALYSIS
                     ---------------------


  ARE YOU EVALUATING A TROPOSCATTER LINK ?  [ N]       Y - YES
                                                       N - NO


IF YES,

   ENTER THE TRANSMITTER ANTENNA 3 dB BEAMWIDTH:  [       ]  ( DEG)

   ENTER THE RECEIVER ANTENNA 3 dB BEAMWIDTH:     [       ]  ( DEG)
```

TABLE 4-1 (Con't)

EXAMPLE OF ECAC INPUT FILES

```
                        -------------------------
                        GROUND CONSTANTS INPUTS
                        -------------------------


     ENTER EITHER THE CCIR GROUND TYPE OR THE GROUND CONSTANTS:

 A - SEA WATER (20 DEGREES C)        E - VERY DRY GROUND
 B - WET GROUND                      F - PURE WATER (NOT USED)
 C - FRESH WATER (20 DEGREES C)      G - ICE (FRESH WATER, -1 DEGREE C)
 D - MEDIUM DRY GROUND               H - ICE (FRESH WATER, -10 DEGREES C)

                    CCIR GROUND TYPE:  [ A]

                              - OR -

              RELATIVE PERMITTIVITY:     [       ]
              ELECTRICAL CONDUCTIVITY:   [       ]  (SIEMENS/M)
```

```
                    ----------------------------
                    ATMOSPHERIC PARAMETER INPUTS
                    ----------------------------


ENTER THE SEA-LEVEL ATMOSPHERIC REFRACTIVITY:  [ 350.]  (N-UNITS)



FOR FREQUENCY GREATER THAN 1 GHZ
ENTER THE LOCAL SURFACE HUMIDITY:    [ 10 ]  (GRAMS/CUBIC METER)
```

TABLE 4-1 (Con't)

EXAMPLE OF ECAC INPUT FILES

```
                        ---------------------------------------
                        PROFILE TYPE / TOPOGRAPHIC FILE INPUTS
                        ---------------------------------------
                         ENTER THE TYPE OF PROFILE TO BE USED:

                           [ 2]  1 - TOPOGRAPHIC FILE PROFILE
                                 2 - USER-ENTERED PROFILE


                            FOR TOPOGRAPHIC FILE PROFILE:
                            -----------------------------

ENTER THE TOPOGRAPHIC DEFAULT ELEVATION (OPTIONAL):  [        ]  ( FT)




                  --------------------------------
                  USER-ENTERED PROFILE TYPE INPUTS
                  --------------------------------

     ENTER THE TYPE OF USER-ENTERED PROFILE:    [ 2]

       1 - EQUALLY-SPACED PROFILE

         ENTER THE DISTANCE BETWEEN PROFILE
         POINTS FOR EQUALLY-SPACED PROFILE:     [       ]  ( SM)

         ENTER THE UNITS FOR ELEVATIONS:        [ FT]

       2 - UNEQUALLY-SPACED PROFILE

         ENTER TRANSMITTER SITE ELEVATION FOR
         UNEQUALLY-SPACED PROFILE (POINT 1):    [ 400   ]  ( FT)

         ENTER THE UNITS FOR DISTANCES:         [ SM]
```

TABLE 4-1 (Con't)

EXAMPLE OF ECAC INPUT FILES

```
                 ----------------------------------------------
                 USER-ENTERED, UNEQUALLY-SPACED PROFILE INPUTS
                 ----------------------------------------------

ENTER DISTANCE BETWEEN POINTS AND PROFILE ELEVATIONS FOR POINTS 2     - 9    :

               DISTANCE UNITS:  SM          ELEVATION UNITS:  FT

================================================================================
!                                      !                                       !
   DIST:  3                ELEV:  300  !  DIST:  2                ELEV:  200   !
--------------------------------------------------------------------------------
!                                      !                                       !
!  DIST:  20               ELEV:  150  !  DIST:  1.5              ELEV:  350   !
--------------------------------------------------------------------------------
!                                      !                                       !
!  DIST:  3.5              ELEV:  400  !  DIST:                   ELEV:        !
--------------------------------------------------------------------------------
!                                      !                                       !
!  DIST:                   ELEV:       !  DIST:                   ELEV:        !
================================================================================

      *** THE LAST ELEVATION ENTERED MUST BE THE RX SITE ELEVATION ***



                              -------------------
                              VARIABILITY OPTIONS
                              -------------------

                          ENTER THE VARIABILITY OPTION:

                      [ 1] 1 - LONG-TERM POWER-FADING STATISTICS

                           2 - MODELING VARIABILITY

                           3 - NO VARIABILITY CONSIDERED



 ENTER THE PERCENTAGE OF A YEAR FOR WHICH THE LOSS IS NOT EXCEEDED:  [ 99.   ]
```

TABLE 4-1 (Con't)

EXAMPLE OF ECAC INPUT FILES

```
                    ---------------------
                    CLIMATIC ZONE INPUTS
                    ---------------------



              1 - CONTINENTAL TEMPERATE
              2 - MARITIME TEMPERATE OVER LAND
              3 - MARITIME TEMPERATE OVER WATER
              4 - MARITIME SUBTROPICAL OVER LAND
              5 - MEDITERRANEAN (NOT USED; USE 3 OR 4)
              6 - DESERT
              7 - EQUATORIAL
              8 - CONTINENTAL SUBTROPICAL


              ENTER THE CLIMATIC ZONE:   [ 1]
```

```
         -----------------------------------------
         PARAMETER INCREMENT / DECREMENT OPTIONS
         -----------------------------------------

    ENTER THE PARAMETER TO BE INCREMENTED/DECREMENTED:

       [ 2]   0 - NO PARAMETER INCREMENTING/DECREMENTING

              1 - PROFILE ENDPOINTS (DECREMENTING)

              2 - FREQUENCY

              3 - TRANSMITTER ANTENNA STRUCTURAL HEIGHT

              4 - RECEIVER ANTENNA STRUCTURAL HEIGHT

              5 - VARIABILITY PERCENTAGE
```

TABLE 4-1 (Con't)

EXAMPLE OF ECAC INPUT FILES

```
                  ----------------------------------------
                  FREQUENCY INCREMENT / DECREMENT INPUTS
                  ----------------------------------------

        ============================================================
        :                                                          :
        :          CURRENT FREQUENCY:    1000.              (MHZ)  :
        :            ALLOWABLE RANGE:      20.00 - 20000.   (MHZ)  :
        :                                                          :
        ============================================================


               ENTER THE FINAL FREQUENCY VALUE:  [ 12000    ]  (MHZ)

           ENTER THE INCREMENT/DECREMENT VALUE:  [ 500   ]      (MHZ)

    CHOOSE THE TYPE OF INCREMENT/DECREMENT:  [ +]  + --> ADDITION
                                                   - --> SUBTRACTION
                                                   * --> MULTIPLICATION
                                                   / --> DIVISION




                                  ---------------
                                  OUTPUT OPTIONS
                                  ---------------

  OUTPUT FROM TIREM CAN BE SENT TO THE SCREEN (IN FULL-SCREEN FORMAT),
  TO AN ASCII FILE, TO A PLOT FILE, OR ANY COMBINATION OF THE ABOVE.
  WHEN INCREMENTING / DECREMENTING A PARAMETER, A RESULTS SCREEN FOR
  EACH VALID VALUE OF THE PARAMETER IS GENERATED.  IN FULL-SCREEN
  OUTPUT FORMAT, THE USER HITS TRANSMIT TO SEE EACH OF THESE RESULTS
  SCREENS IN SUCCESSION.


                      ENTER AN X IN THE DESIRED BOXES:

     [ X]  OUTPUT RESULTS TO SCREEN IN FULL-SCREEN FORMAT
     [ X]  OUTPUT RESULTS TO AN ASCII OUTPUT FILE
             ENTER ASCII FILE NAME:  [ sea.OUT                            ]

     [  ]  OUTPUT PROFILE TO PLOT FILE
             ENTER PLOT FILE NAME:   [ sea.PLT                            ]
```

TABLE 4-1 (Con't)

EXAMPLE OF ECAC INPUT FILES

```
          **********  TTP  TIREM INPUT PARAMETERS *********
                          [ VERSION: 1.0 ]
---------------------------------------------------------------------------
 GENERAL PARAMETERS:

  TOPOGRAPHIC DATA FILE: USER-ENTERED  PERMITTIVITY: 69.18311
  DATUM CODE: 0                        CONDUCTIVITY:  5.01187 (SIEMENS/M)
  CLIMATIC ZONE: 1                     REFRACTIVITY:     350. (N-UNITS)
  VARIABILTY PERCENT:  99.    (%)      HUMIDITY:          10. (GM/M**3)
---------------------------------------------------------------------------
 TRANSMITTER PARAMETERS:              RECEIVER PARAMETERS:

  IDENTIFIER:         [ TRANSMIT ]     IDENTIFIER:          [ RECEIVER ]
  ANTENNA HEIGHT:     50.       (FT)   ANTENNA HEIGHT:      50.      (FT)
  SITE ELEVATION:       400.    (FT)   SITE ELEVATION:        400.   (FT)
  LOCATION:    -  -  -      -  -  -    LOCATION:    -  -  -      -  -  -
  MAXIMUM ANT DIM:    10.       (FT)   MAXIMUM ANT DIM:     10.      (FT)
  ANTENNA GAIN:          20.    (dBi)  ANTENNA GAIN:           20.   (dBi)
  FREQUENCY:          1000.    (MHZ)
  POWER:              25.       ( W )
  POLARIZATION: [V]                          ** TRANSMIT TO CONTINUE **
---------------------------------------------------------------------------
```

TABLE 4-2

EXAMPLE OF ECAC RESULTS FILES

```
      **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
---------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY          CURRENT VALUE:     1000.   (MHZ)
  INCRMT/DECRMT VALUE: 500.   (MHZ)       INCRMT/DECRMT TYPE: [+]
---------------------------------------------------------------------------
  OUTPUT PARAMETERS:                           POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                  (DEG)      (%)     |   BASIC LOSS
   RX TAKE-OFF ANGLE:                  (DEG)   -------------------------
   NEAR FLD BOUNDARY-TX:        203.65 (FT)       0.01    |     116.2
   NEAR FLD BOUNDARY-RX:        203.65 (FT)       0.10    |     119.4
   PATH LENGTH:             30.        (SM)       1.00    |     123.3
   PROPAGATION LOSS:             133.8 (dB)      10.00    |     128.5
   FREE-SPACE  LOSS:             126.1 (dB)      50.00    |     133.8
   ABSORPTION  LOSS:                .3 (dB)      90.00    |     136.9
   BEARING  (TX-RX):           .00     (DEG)     99.00    |     139.6
   SCATTERING ANGLE:         -.036171  (DEG)     99.90    |     141.5
   FIELD STRENGTH:             .00171  (V/M)     99.99    |     143.0
   POWER DENSITY:        -55.       (dBm/M**2)   99.00    |     139.6
---------------------------------------------------------------------------

      **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
---------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY          CURRENT VALUE:     1500.   (MHZ)
  INCRMT/DECRMT VALUE: 500.   (MHZ)       INCRMT/DECRMT TYPE: [+]
---------------------------------------------------------------------------
  OUTPUT PARAMETERS:                           POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                  (DEG)      (%)     |   BASIC LOSS
   RX TAKE-OFF ANGLE:                  (DEG)   -------------------------
   NEAR FLD BOUNDARY-TX:        305.47 (FT)       0.01    |     121.3
   NEAR FLD BOUNDARY-RX:        305.47 (FT)       0.10    |     124.0
   PATH LENGTH:             30.        (SM)       1.00    |     127.3
   PROPAGATION LOSS:             136.3 (dB)      10.00    |     131.8
   FREE-SPACE  LOSS:             129.6 (dB)      50.00    |     136.3
   ABSORPTION  LOSS:                .3 (dB)      90.00    |     139.2
   BEARING  (TX-RX):           .00     (DEG)     99.00    |     141.6
   SCATTERING ANGLE:         -.036171  (DEG)     99.90    |     143.3
   FIELD STRENGTH:             .00205  (V/M)     99.99    |     144.7
   POWER DENSITY:        -53.       (dBm/M**2)   99.00    |     141.6
---------------------------------------------------------------------------

                                          ** TRANSMIT TO CONTINUE **
---------------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
        **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
---------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY         CURRENT VALUE:     2000.    (MHZ)
  INCRMT/DECRMT VALUE: 500.    (MHZ)     INCRMT/DECRMT TYPE: [+]
---------------------------------------------------------------------------
  OUTPUT PARAMETERS:                          POWER FADING STATISTICS:
   PROPAGATION MODE:   LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                 (DEG)      (%)     !   BASIC LOSS
   RX TAKE-OFF ANGLE:                 (DEG)   --------------------------
   NEAR FLD BOUNDARY-TX:       407.30 (FT)      0.01     !     122.3
   NEAR FLD BOUNDARY-RX:       407.30 (FT)      0.10     !     125.1
   PATH LENGTH:            30.        (SM)      1.00     !     128.5
   PROPAGATION LOSS:            137.9 (dB)     10.00     !     133.2
   FREE-SPACE  LOSS:            132.1 (dB)     50.00     !     137.9
   ABSORPTION  LOSS:               .4 (dB)     90.00     !     140.9
   BEARING  (TX-RX):         .00      (DEG)    99.00     !     143.4
   SCATTERING ANGLE:       -.036171   (DEG)    99.90     !     145.2
   FIELD STRENGTH:           .00221   (V/M)    99.99     !     146.7
   POWER DENSITY:       -52.       (dBm/M**2)  99.00     !     143.4
---------------------------------------------------------------------------

        **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
---------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY         CURRENT VALUE:     2500.    (MHZ)
  INCRMT/DECRMT VALUE: 500.    (MHZ)     INCRMT/DECRMT TYPE: [+]
---------------------------------------------------------------------------
  OUTPUT PARAMETERS:                          POWER FADING STATISTICS:
   PROPAGATION MODE:   LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                 (DEG)      (%)     !   BASIC LOSS
   RX TAKE-OFF ANGLE:                 (DEG)   --------------------------
   NEAR FLD BOUNDARY-TX:       509.12 (FT)      0.01     !     123.0
   NEAR FLD BOUNDARY-RX:       509.12 (FT)      0.10     !     125.9
   PATH LENGTH:            30.        (SM)      1.00     !     129.5
   PROPAGATION LOSS:            139.2 (dB)     10.00     !     134.3
   FREE-SPACE  LOSS:            134.1 (dB)     50.00     !     139.1
   ABSORPTION  LOSS:               .4 (dB)     90.00     !     142.2
   BEARING  (TX-RX):         .00      (DEG)    99.00     !     144.8
   SCATTERING ANGLE:       -.036171   (DEG)    99.90     !     146.7
   FIELD STRENGTH:           .00234   (V/M)    99.99     !     148.2
   POWER DENSITY:       -52.       (dBm/M**2)  99.00     !     144.8
---------------------------------------------------------------------------

                                          ** TRANSMIT TO CONTINUE **
---------------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
         **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
------------------------------------------------------------------------------
   STEPPING PARAMETER:  FREQUENCY          CURRENT VALUE:     3000.    (MHZ)
   INCRMT/DECRMT VALUE: 500.    (MHZ)      INCRMT/DECRMT TYPE: [+]
------------------------------------------------------------------------------
   OUTPUT PARAMETERS:                           POWER FADING STATISTICS:
    PROPAGATION MODE:    LINE-OF-SIGHT
    TX TAKE-OFF ANGLE:                (DEG)       (%)     !   BASIC LOSS
    RX TAKE-OFF ANGLE:                (DEG)   --------------------------
    NEAR FLD BOUNDARY-TX:       610.95 (FT)       0.01    !      123.7
    NEAR FLD BOUNDARY-RX:       610.95 (FT)       0.10    !      126.7
    PATH LENGTH:            30.        (SM)       1.00    !      130.3
    PROPAGATION LOSS:            140.2 (dB)      10.00    !      135.2
    FREE-SPACE  LOSS:            135.7 (dB)      50.00    !      140.1
    ABSORPTION  LOSS:               .5 (dB)      90.00    !      143.3
    BEARING  (TX-RX):          .00     (DEG)     99.00    !      146.0
    SCATTERING ANGLE:        -.036171  (DEG)     99.90    !      147.9
    FIELD STRENGTH:             .00245 (V/M)     99.99    !      149.5
    POWER DENSITY:       -51.     (dBm/M**2)     99.00    !      146.0
------------------------------------------------------------------------------

         **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
------------------------------------------------------------------------------
   STEPPING PARAMETER:  FREQUENCY          CURRENT VALUE:     3500.    (MHZ)
   INCRMT/DECRMT VALUE: 500.    (MHZ)      INCRMT/DECRMT TYPE: [+]
------------------------------------------------------------------------------
   OUTPUT PARAMETERS:                           POWER FADING STATISTICS:
    PROPAGATION MODE:    LINE-OF-SIGHT
    TX TAKE-OFF ANGLE:                (DEG)       (%)     !   BASIC LOSS
    RX TAKE-OFF ANGLE:                (DEG)   --------------------------
    NEAR FLD BOUNDARY-TX:       712.77 (FT)       0.01    !      124.3
    NEAR FLD BOUNDARY-RX:       712.77 (FT)       0.10    !      127.3
    PATH LENGTH:            30.        (SM)       1.00    !      131.0
    PROPAGATION LOSS:            141.1 (dB)      10.00    !      136.0
    FREE-SPACE  LOSS:            137.0 (dB)      50.00    !      141.0
    ABSORPTION  LOSS:               .6 (dB)      90.00    !      144.3
    BEARING  (TX-RX):          .00     (DEG)     99.00    !      147.0
    SCATTERING ANGLE:        -.036171  (DEG)     99.90    !      149.0
    FIELD STRENGTH:             .00255 (V/M)     99.99    !      150.6
    POWER DENSITY:       -51.     (dBm/M**2)     99.00    !      147.0
------------------------------------------------------------------------------

                                              ** TRANSMIT TO CONTINUE **
------------------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
          **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
--------------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY          CURRENT VALUE:    4000.    (MHZ)
  INCRMT/DECRMT VALUE: 500.    (MHZ)      INCRMT/DECRMT TYPE: [+]
--------------------------------------------------------------------------------
  OUTPUT PARAMETERS:                                  POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                    (DEG)       (%)     |   BASIC LOSS
   RX TAKE-OFF ANGLE:                    (DEG)    --------------------------
   NEAR FLD BOUNDARY-TX:         814.60  (FT)       0.01     |     124.8
   NEAR FLD BOUNDARY-RX:         814.60  (FT)       0.10     |     127.9
   PATH LENGTH:               30.        (SM)       1.00     |     131.6
   PROPAGATION LOSS:              141.9  (dB)      10.00     |     136.7
   FREE-SPACE  LOSS:              138.2  (dB)      50.00     |     141.8
   ABSORPTION  LOSS:                 .6  (dB)      90.00     |     145.1
   BEARING  (TX-RX):            .00      (DEG)     99.00     |     147.9
   SCATTERING ANGLE:          -.036171   (DEG)     99.90     |     149.9
   FIELD STRENGTH:              .00263   (V/M)     99.99     |     151.5
   POWER DENSITY:        -51.        (dBm/M**2)    99.00     |     147.9
--------------------------------------------------------------------------------

          **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
--------------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY          CURRENT VALUE:    4500.    (MHZ)
  INCRMT/DECRMT VALUE: 500.    (MHZ)      INCRMT/DECRMT TYPE: [+]
--------------------------------------------------------------------------------
  OUTPUT PARAMETERS:                                  POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                    (DEG)       (%)     |   BASIC LOSS
   RX TAKE-OFF ANGLE:                    (DEG)    --------------------------
   NEAR FLD BOUNDARY-TX:         916.42  (FT)       0.01     |     125.3
   NEAR FLD BOUNDARY-RX:         916.42  (FT)       0.10     |     128.4
   PATH LENGTH:               30.        (SM)       1.00     |     132.1
   PROPAGATION LOSS:              142.6  (dB)      10.00     |     137.3
   FREE-SPACE  LOSS:              139.2  (dB)      50.00     |     142.4
   ABSORPTION  LOSS:                 .7  (dB)      90.00     |     145.9
   BEARING  (TX-RX):            .00      (DEG)     99.00     |     148.7
   SCATTERING ANGLE:          -.036171   (DEG)     99.90     |     150.7
   FIELD STRENGTH:              .00271   (V/M)     99.99     |     152.4
   POWER DENSITY:        -51.        (dBm/M**2)    99.00     |     148.7
--------------------------------------------------------------------------------

                                              ** TRANSMIT TO CONTINUE **
--------------------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
           **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
-----------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY           CURRENT VALUE:    5000.   (MHZ)
  INCRMT/DECRMT VALUE: 500.   (MHZ)        INCRMT/DECRMT TYPE: [+]
-----------------------------------------------------------------------------
  OUTPUT PARAMETERS:                            POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                  (DEG)      (%)     !   BASIC LOSS
   RX TAKE-OFF ANGLE:                  (DEG)    -------------------------
   NEAR FLD BOUNDARY-TX:      1018.25  (FT)       0.01    !     125.7
   NEAR FLD BOUNDARY-RX:      1018.25  (FT)       0.10    !     128.8
   PATH LENGTH:             30.        (SM)       1.00    !     132.6
   PROPAGATION LOSS:            143.2  (dB)      10.00    !     137.8
   FREE-SPACE  LOSS:            140.1  (dB)      50.00    !     143.1
   ABSORPTION  LOSS:               .7  (dB)      90.00    !     146.5
   BEARING  (TX-RX):          .00      (DEG)     99.00    !     149.4
   SCATTERING ANGLE:        -.036171   (DEG)     99.90    !     151.4
   FIELD STRENGTH:            .00277   (V/M)     99.99    !     153.1
   POWER DENSITY:       -50.       (dBm/M**2)    99.00    !     149.4
-----------------------------------------------------------------------------

           **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
-----------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY           CURRENT VALUE:    5500.   (MHZ)
  INCRMT/DECRMT VALUE: 500.   (MHZ)        INCRMT/DECRMT TYPE: [+]
-----------------------------------------------------------------------------
  OUTPUT PARAMETERS:                            POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                  (DEG)      (%)     !   BASIC LOSS
   RX TAKE-OFF ANGLE:                  (DEG)    -------------------------
   NEAR FLD BOUNDARY-TX:      1120.07  (FT)       0.01    !     126.1
   NEAR FLD BOUNDARY-RX:      1120.07  (FT)       0.10    !     129.2
   PATH LENGTH:             30.        (SM)       1.00    !     133.1
   PROPAGATION LOSS:            143.8  (dB)      10.00    !     138.3
   FREE-SPACE  LOSS:            140.9  (dB)      50.00    !     143.6
   ABSORPTION  LOSS:               .8  (dB)      90.00    !     147.1
   BEARING  (TX-RX):          .00      (DEG)     99.00    !     150.0
   SCATTERING ANGLE:        -.036171   (DEG)     99.90    !     152.1
   FIELD STRENGTH:            .00284   (V/M)     99.99    !     153.8
   POWER DENSITY:       -50.       (dBm/M**2)    99.00    !     150.0
-----------------------------------------------------------------------------

                                           ** TRANSMIT TO CONTINUE **
-----------------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
        **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
---------------------------------------------------------------------------
   STEPPING PARAMETER:  FREQUENCY            CURRENT VALUE:     6000.   (MHZ)
   INCRMT/DECRMT VALUE: 500.   (MHZ)         INCRMT/DECRMT TYPE: [+]
---------------------------------------------------------------------------
   OUTPUT PARAMETERS:                             POWER FADING STATISTICS:
    PROPAGATION MODE:    LINE-OF-SIGHT
    TX TAKE-OFF ANGLE:                    (DEG)       (%)      !   BASIC LOSS
    RX TAKE-OFF ANGLE:                    (DEG)   ---------------------------
    NEAR FLD BOUNDARY-TX:         1221.90 (FT)       0.01      !      126.5
    NEAR FLD BOUNDARY-RX:         1221.90 (FT)       0.10      !      129.6
    PATH LENGTH:              30.         (SM)       1.00      !      133.5
    PROPAGATION LOSS:               144.3 (dB)      10.00      !      138.8
    FREE-SPACE  LOSS:               141.7 (dB)      50.00      !      144.1
    ABSORPTION  LOSS:                  .8 (dB)      90.00      !      147.7
    BEARING  (TX-RX):            .00      (DEG)     99.00      !      150.6
    SCATTERING ANGLE:           -.036171  (DEG)     99.90      !      152.7
    FIELD STRENGTH:               .00290  (V/M)     99.99      !      154.4
    POWER DENSITY:         -50.       (dBm/M**2)    99.00      !      150.6
---------------------------------------------------------------------------

        **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
---------------------------------------------------------------------------
   STEPPING PARAMETER:  FREQUENCY            CURRENT VALUE:     6500.   (MHZ)
   INCRMT/DECRMT VALUE: 500.   (MHZ)         INCRMT/DECRMT TYPE: [+]
---------------------------------------------------------------------------
   OUTPUT PARAMETERS:                             POWER FADING STATISTICS:
    PROPAGATION MODE:    LINE-OF-SIGHT
    TX TAKE-OFF ANGLE:                    (DEG)       (%)      !   BASIC LOSS
    RX TAKE-OFF ANGLE:                    (DEG)   ---------------------------
    NEAR FLD BOUNDARY-TX:         1323.72 (FT)       0.01      !      126.8
    NEAR FLD BOUNDARY-RX:         1323.72 (FT)       0.10      !      130.0
    PATH LENGTH:              30.         (SM)       1.00      !      133.9
    PROPAGATION LOSS:               144.7 (dB)      10.00      !      139.2
    FREE-SPACE  LOSS:               142.4 (dB)      50.00      !      144.6
    ABSORPTION  LOSS:                  .9 (dB)      90.00      !      148.2
    BEARING  (TX-RX):            .00      (DEG)     99.00      !      151.1
    SCATTERING ANGLE:           -.036171  (DEG)     99.90      !      153.2
    FIELD STRENGTH:               .00295  (V/M)     99.99      !      155.0
    POWER DENSITY:         -50.       (dBm/M**2)    99.00      !      151.1
---------------------------------------------------------------------------

                                         ** TRANSMIT TO CONTINUE **
---------------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
       **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
-----------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY           CURRENT VALUE:    7000.   (MHZ)
  INCRMT/DECRMT VALUE: 500.   (MHZ)        INCRMT/DECRMT TYPE: [+]
-----------------------------------------------------------------------------
  OUTPUT PARAMETERS:                           POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                   (DEG)     (%)    :   BASIC LOSS
   RX TAKE-OFF ANGLE:                   (DEG)   ---------------------------
   NEAR FLD BOUNDARY-TX:      1425.55  (FT)      0.01    :      127.1
   NEAR FLD BOUNDARY-RX:      1425.55  (FT)      0.10    :      130.3
   PATH LENGTH:             30.         (SM)      1.00    :      134.3
   PROPAGATION LOSS:            145.2  (dB)     10.00    :      139.7
   FREE-SPACE  LOSS:            143.0  (dB)     50.00    :      145.0
   ABSORPTION  LOSS:               .9  (dB)     90.00    :      148.6
   BEARING  (TX-RX):          .00       (DEG)    99.00    :      151.6
   SCATTERING ANGLE:         -.036171  (DEG)    99.90    :      153.7
   FIELD STRENGTH:             .00300  (V/M)    99.99    :      155.5
   POWER DENSITY:        -50.      (dBm/M**2)   99.00    :      151.6
-----------------------------------------------------------------------------

       **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
-----------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY           CURRENT VALUE:    7500.   (MHZ)
  INCRMT/DECRMT VALUE: 500.   (MHZ)        INCRMT/DECRMT TYPE: [+]
-----------------------------------------------------------------------------
  OUTPUT PARAMETERS:                           POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                   (DEG)     (%)    :   BASIC LOSS
   RX TAKE-OFF ANGLE:                   (DEG)   ---------------------------
   NEAR FLD BOUNDARY-TX:      1527.37  (FT)      0.01    :      127.4
   NEAR FLD BOUNDARY-RX:      1527.37  (FT)      0.10    :      130.7
   PATH LENGTH:             30.         (SM)      1.00    :      134.6
   PROPAGATION LOSS:            145.6  (dB)     10.00    :      140.0
   FREE-SPACE  LOSS:            143.6  (dB)     50.00    :      145.5
   ABSORPTION  LOSS:               .9  (dB)     90.00    :      149.1
   BEARING  (TX-RX):          .00       (DEG)    99.00    :      152.1
   SCATTERING ANGLE:         -.036171  (DEG)    99.90    :      154.2
   FIELD STRENGTH:             .00305  (V/M)    99.99    :      156.0
   POWER DENSITY:        -50.      (dBm/M**2)   99.00    :      152.1
-----------------------------------------------------------------------------

                                         ** TRANSMIT TO CONTINUE **
-----------------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
     **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
-------------------------------------------------------------------------
 STEPPING PARAMETER:  FREQUENCY         CURRENT VALUE:    8000.   (MHZ)
 INCRMT/DECRMT VALUE: 500.   (MHZ)      INCRMT/DECRMT TYPE: [+]
-------------------------------------------------------------------------
 OUTPUT PARAMETERS:                               POWER FADING STATISTICS:
  PROPAGATION MODE:    LINE-OF-SIGHT
  TX TAKE-OFF ANGLE:                 (DEG)      (%)     !   BASIC LOSS
  RX TAKE-OFF ANGLE:                 (DEG)   --------------------------
  NEAR FLD BOUNDARY-TX:      1629.20 (FT)       0.01    !     127.7
  NEAR FLD BOUNDARY-RX:      1629.20 (FT)       0.10    !     131.0
  PATH LENGTH:             30.       (SM)       1.00    !     135.0
  PROPAGATION LOSS:            146.0 (dB)      10.00    !     140.4
  FREE-SPACE  LOSS:            144.2 (dB)      50.00    !     145.9
  ABSORPTION  LOSS:              1.0 (dB)      90.00    !     149.5
  BEARING  (TX-RX):          .00     (DEG)     99.00    !     152.5
  SCATTERING ANGLE:         -.036171 (DEG)     99.90    !     154.7
  FIELD STRENGTH:             .00309 (V/M)     99.99    !     156.5
  POWER DENSITY:       -49.     (dBm/M**2)     99.00    !     152.5
-------------------------------------------------------------------------

     **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
-------------------------------------------------------------------------
 STEPPING PARAMETER:  FREQUENCY         CURRENT VALUE:    8500.   (MHZ)
 INCRMT/DECRMT VALUE: 500.   (MHZ)      INCRMT/DECRMT TYPE: [+]
-------------------------------------------------------------------------
 OUTPUT PARAMETERS:                               POWER FADING STATISTICS:
  PROPAGATION MODE:    LINE-OF-SIGHT
  TX TAKE-OFF ANGLE:                 (DEG)      (%)     !   BASIC LOSS
  RX TAKE-OFF ANGLE:                 (DEG)   --------------------------
  NEAR FLD BOUNDARY-TX:      1731.02 (FT)       0.01    !     128.0
  NEAR FLD BOUNDARY-RX:      1731.02 (FT)       0.10    !     131.3
  PATH LENGTH:             30.       (SM)       1.00    !     135.3
  PROPAGATION LOSS:            146.4 (dB)      10.00    !     140.8
  FREE-SPACE  LOSS:            144.7 (dB)      50.00    !     146.2
  ABSORPTION  LOSS:              1.0 (dB)      90.00    !     149.9
  BEARING  (TX-RX):          .00     (DEG)     99.00    !     152.9
  SCATTERING ANGLE:         -.036171 (DEG)     99.90    !     155.1
  FIELD STRENGTH:             .00313 (V/M)     99.99    !     156.9
  POWER DENSITY:       -49.     (dBm/M**2)     99.00    !     152.9
-------------------------------------------------------------------------

                                          ** TRANSMIT TO CONTINUE **
-------------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
      **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
---------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY          CURRENT VALUE:     9000.   (MHZ)
  INCRMT/DECRMT VALUE: 500.   (MHZ)       INCRMT/DECRMT TYPE: [+]
---------------------------------------------------------------------------
  OUTPUT PARAMETERS:                          POWER FADING STATISTICS:
   PROPAGATION MODE:     LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                  (DEG)       (%)     :   BASIC LOSS
   RX TAKE-OFF ANGLE:                  (DEG)    --------------------------
   NEAR FLD BOUNDARY-TX:       1832.84 (FT)       0.01     :      128.3
   NEAR FLD BOUNDARY-RX:       1832.84 (FT)       0.10     :      131.6
   PATH LENGTH:              30.       (SM)       1.00     :      135.6
   PROPAGATION LOSS:             146.8 (dB)      10.00     :      141.1
   FREE-SPACE  LOSS:             145.2 (dB)      50.00     :      146.6
   ABSORPTION  LOSS:               1.0 (dB)      90.00     :      150.3
   BEARING  (TX-RX):           .00     (DEG)     99.00     :      153.3
   SCATTERING ANGLE:         -.036171  (DEG)     99.90     :      155.5
   FIELD STRENGTH:             .00316  (V/M)     99.99     :      157.3
   POWER DENSITY:         -49.      (dBm/M**2)   99.00     :      153.3
---------------------------------------------------------------------------

      **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
---------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY          CURRENT VALUE:     9500.   (MHZ)
  INCRMT/DECRMT VALUE: 500.   (MHZ)       INCRMT/DECRMT TYPE: [+]
---------------------------------------------------------------------------
  OUTPUT PARAMETERS:                          POWER FADING STATISTICS:
   PROPAGATION MODE:     LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                  (DEG)       (%)     :   BASIC LOSS
   RX TAKE-OFF ANGLE:                  (DEG)    --------------------------
   NEAR FLD BOUNDARY-TX:       1934.67 (FT)       0.01     :      128.5
   NEAR FLD BOUNDARY-RX:       1934.67 (FT)       0.10     :      131.8
   PATH LENGTH:              30.       (SM)       1.00     :      135.9
   PROPAGATION LOSS:             147.1 (dB)      10.00     :      141.4
   FREE-SPACE  LOSS:             145.7 (dB)      50.00     :      146.9
   ABSORPTION  LOSS:               1.1 (dB)      90.00     :      150.7
   BEARING  (TX-RX):           .00     (DEG)     99.00     :      153.7
   SCATTERING ANGLE:         -.036171  (DEG)     99.90     :      155.9
   FIELD STRENGTH:             .00319  (V/M)     99.99     :      157.8
   POWER DENSITY:         -49.      (dBm/M**2)   99.00     :      153.7
---------------------------------------------------------------------------

                                       ** TRANSMIT TO CONTINUE **
---------------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
        **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
--------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY           CURRENT VALUE:     10000.  (MHZ)
  INCRMT/DECRMT VALUE: 500.    (MHZ)       INCRMT/DECRMT TYPE: [+]
--------------------------------------------------------------------------
  OUTPUT PARAMETERS:                             POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                  (DEG)      (%)     |   BASIC LOSS
   RX TAKE-OFF ANGLE:                  (DEG)    --------------------------
   NEAR FLD BOUNDARY-TX:       2036.49 (FT)      0.01     |     128.8
   NEAR FLD BOUNDARY-RX:       2036.49 (FT)      0.10     |     132.1
   PATH LENGTH:             30.        (SM)      1.00     |     136.2
   PROPAGATION LOSS:             147.5 (dB)     10.00     |     141.7
   FREE-SPACE  LOSS:             146.1 (dB)     50.00     |     147.3
   ABSORPTION  LOSS:               1.1 (dB)     90.00     |     151.0
   BEARING  (TX-RX):          .00      (DEG)    99.00     |     154.1
   SCATTERING ANGLE:        -.036171   (DEG)    99.90     |     156.3
   FIELD STRENGTH:             .00322  (V/M)    99.99     |     158.1
   POWER DENSITY:         -49.      (dBm/M**2)  99.00     |     154.1
--------------------------------------------------------------------------

        **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
--------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY           CURRENT VALUE:     10500.  (MHZ)
  INCRMT/DECRMT VALUE: 500.    (MHZ)       INCRMT/DECRMT TYPE: [+]
--------------------------------------------------------------------------
  OUTPUT PARAMETERS:                             POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                  (DEG)      (%)     |   BASIC LOSS
   RX TAKE-OFF ANGLE:                  (DEG)    --------------------------
   NEAR FLD BOUNDARY-TX:       2138.32 (FT)      0.01     |     129.1
   NEAR FLD BOUNDARY-RX:       2138.32 (FT)      0.10     |     132.4
   PATH LENGTH:             30.        (SM)      1.00     |     136.5
   PROPAGATION LOSS:             147.8 (dB)     10.00     |     142.1
   FREE-SPACE  LOSS:             146.5 (dB)     50.00     |     147.6
   ABSORPTION  LOSS:               1.2 (dB)     90.00     |     151.4
   BEARING  (TX-RX):          .00      (DEG)    99.00     |     154.5
   SCATTERING ANGLE:        -.036171   (DEG)    99.90     |     156.7
   FIELD STRENGTH:             .00323  (V/M)    99.99     |     158.6
   POWER DENSITY:         -49.      (dBm/M**2)  99.00     |     154.5
--------------------------------------------------------------------------

                                          ** TRANSMIT TO CONTINUE **
--------------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
       **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
-----------------------------------------------------------------------
 STEPPING PARAMETER:  FREQUENCY           CURRENT VALUE:     11000.  (MHZ)
 INCRMT/DECRMT VALUE: 500.   (MHZ)        INCRMT/DECRMT TYPE: [+]
-----------------------------------------------------------------------
 OUTPUT PARAMETERS:                            POWER FADING STATISTICS:
  PROPAGATION MODE:    LINE-OF-SIGHT
  TX TAKE-OFF ANGLE:                  (DEG)      (%)     :   BASIC LOSS
  RX TAKE-OFF ANGLE:                  (DEG)   --------------------------
  NEAR FLD BOUNDARY-TX:       2240.14 (FT)       0.01    :      129.4
  NEAR FLD BOUNDARY-RX:       2240.14 (FT)       0.10    :      132.8
  PATH LENGTH:              30.       (SM)       1.00    :      136.9
  PROPAGATION LOSS:             148.3 (dB)      10.00    :      142.5
  FREE-SPACE  LOSS:             147.0 (dB)      50.00    :      148.1
  ABSORPTION  LOSS:               1.3 (dB)      90.00    :      151.9
  BEARING   (TX-RX):          .00     (DEG)     99.00    :      155.0
  SCATTERING ANGLE:         -.036171  (DEG)     99.90    :      157.2
  FIELD STRENGTH:             .00321  (V/M)     99.99    :      159.0
  POWER DENSITY:         -49.       (dBm/M**2)  99.00    :      155.0
-----------------------------------------------------------------------

       **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
-----------------------------------------------------------------------
 STEPPING PARAMETER:  FREQUENCY           CURRENT VALUE:     11500.  (MHZ)
 INCRMT/DECRMT VALUE: 500.   (MHZ)        INCRMT/DECRMT TYPE: [+]
-----------------------------------------------------------------------
 OUTPUT PARAMETERS:                            POWER FADING STATISTICS:
  PROPAGATION MODE:    LINE-OF-SIGHT
  TX TAKE-OFF ANGLE:                  (DEG)      (%)     :   BASIC LOSS
  RX TAKE-OFF ANGLE:                  (DEG)   --------------------------
  NEAR FLD BOUNDARY-TX:       2341.97 (FT)       0.01    :      129.8
  NEAR FLD BOUNDARY-RX:       2341.97 (FT)       0.10    :      133.2
  PATH LENGTH:              30.       (SM)       1.00    :      137.3
  PROPAGATION LOSS:             148.7 (dB)      10.00    :      142.9
  FREE-SPACE  LOSS:             147.3 (dB)      50.00    :      148.5
  ABSORPTION  LOSS:               1.4 (dB)      90.00    :      152.3
  BEARING   (TX-RX):          .00     (DEG)     99.00    :      155.5
  SCATTERING ANGLE:         -.036171  (DEG)     99.90    :      157.7
  FIELD STRENGTH:             .00316  (V/M)     99.99    :      159.6
  POWER DENSITY:         -49.       (dBm/M**2)  99.00    :      155.5
-----------------------------------------------------------------------

                                        ** TRANSMIT TO CONTINUE **
-----------------------------------------------------------------------
```

TABLE 4-2 (Con't)

EXAMPLE OF ECAC RESULTS FILES

```
        **********  TTP  TIREM RESULTS [VERSION: 1.0] ********
-------------------------------------------------------------------------
  STEPPING PARAMETER:  FREQUENCY          CURRENT VALUE:     12000.  (MHZ)
  INCRMT/DECRMT VALUE: 500.   (MHZ)       INCRMT/DECRMT TYPE: [+]
-------------------------------------------------------------------------
  OUTPUT PARAMETERS:                           POWER FADING STATISTICS:
   PROPAGATION MODE:    LINE-OF-SIGHT
   TX TAKE-OFF ANGLE:                  (DEG)       (%)     ¦   BASIC LOSS
   RX TAKE-OFF ANGLE:                  (DEG)   --------------------------
   NEAR FLD BOUNDARY-TX:      2443.79  (FT)        0.01    ¦     130.2
   NEAR FLD BOUNDARY-RX:      2443.79  (FT)        0.10    ¦     133.6
   PATH LENGTH:             30.        (SM)        1.00    ¦     137.7
   PROPAGATION LOSS:            149.2  (dB)       10.00    ¦     143.4
   FREE-SPACE  LOSS:            147.7  (dB)       50.00    ¦     149.0
   ABSORPTION  LOSS:              1.5  (dB)       90.00    ¦     152.8
   BEARING  (TX-RX):        .00        (DEG)      99.00    ¦     156.0
   SCATTERING ANGLE:       -.036171    (DEG)      99.90    ¦     158.2
   FIELD STRENGTH:           .00312    (V/M)      99.99    ¦     160.1
   POWER DENSITY:      -49.       (dBm/M**2)      99.00    ¦     156.0
-------------------------------------------------------------------------
```

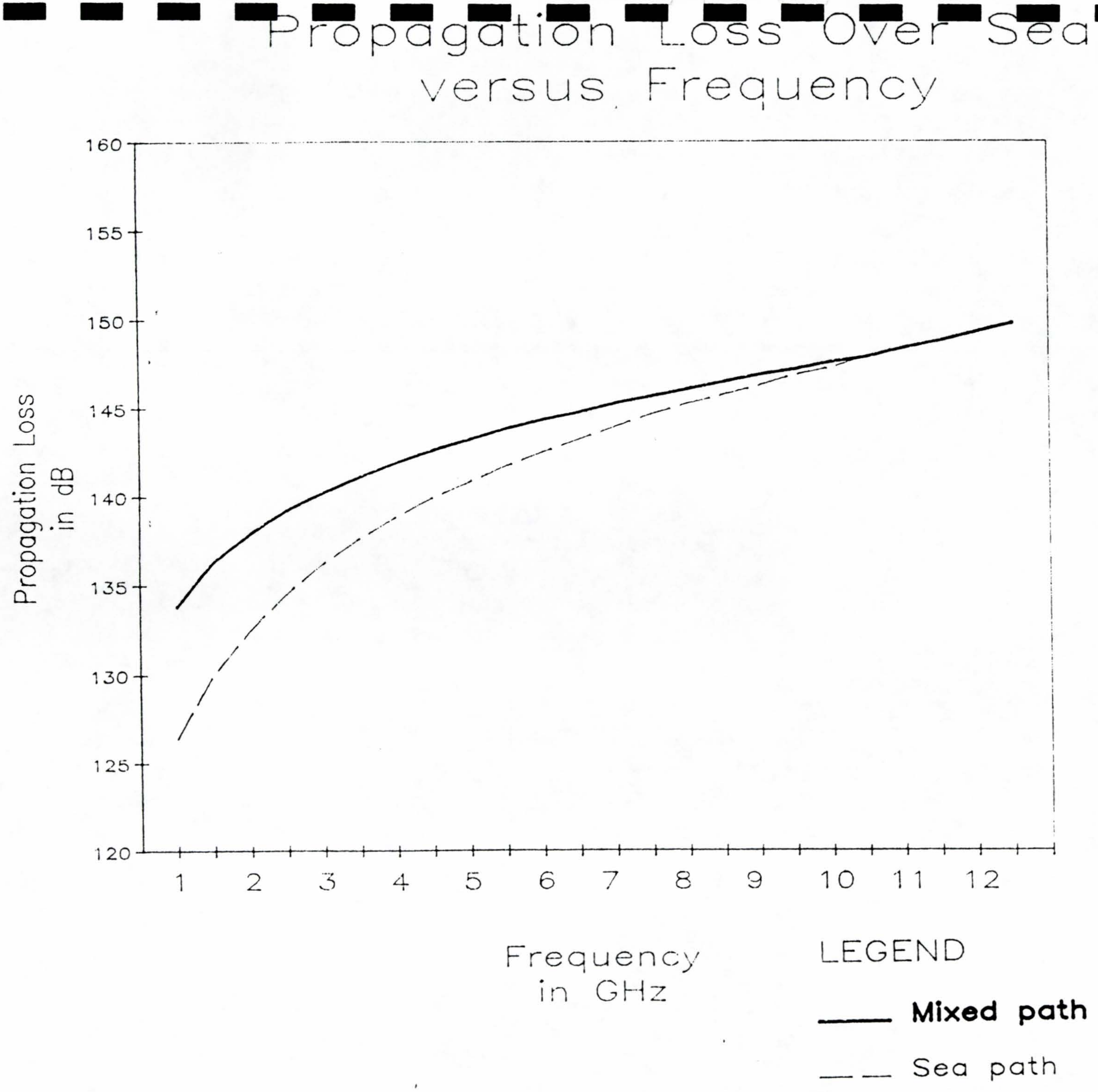


Figure 4-2. Propagation Loss Over Sea.

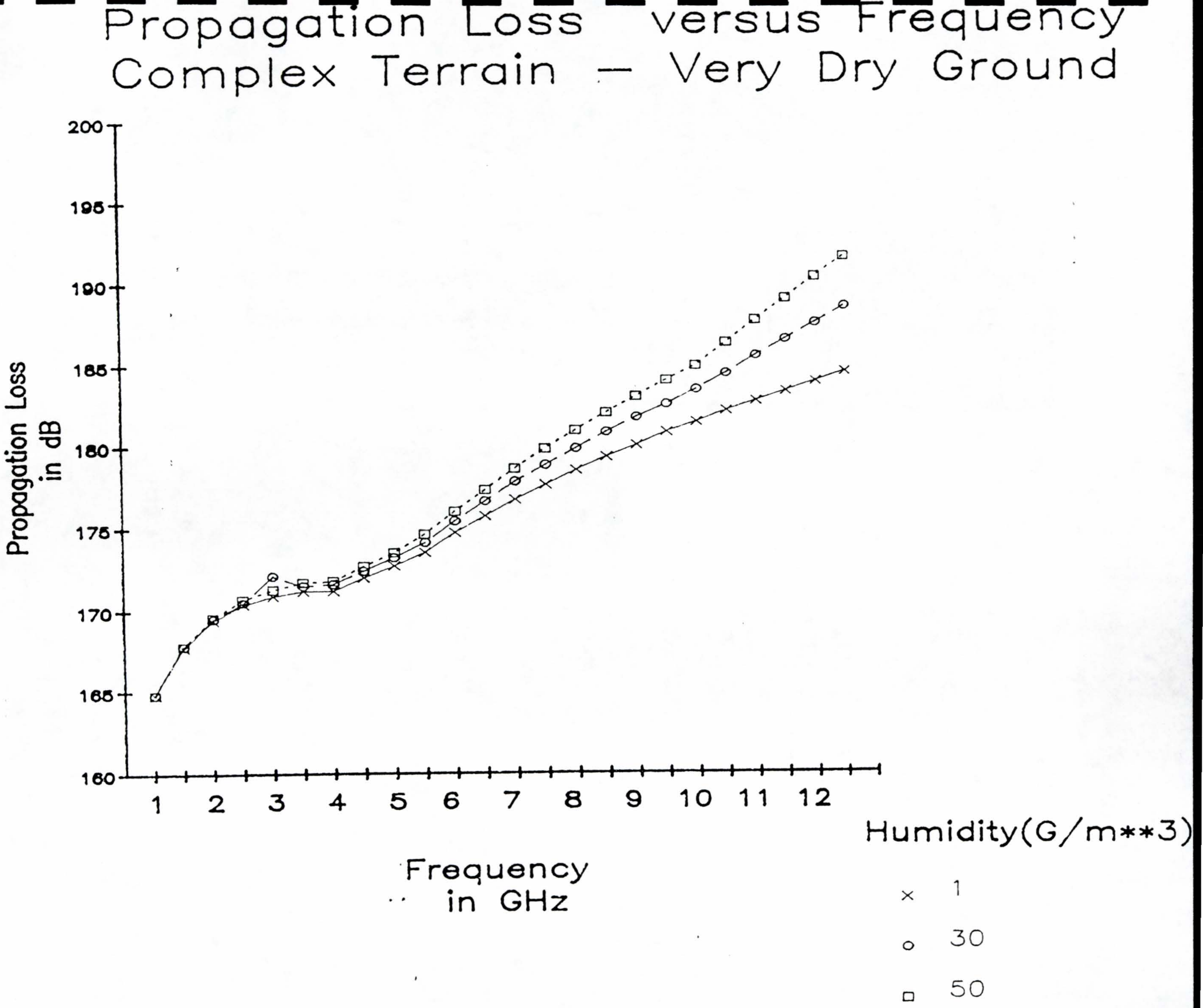


Figure 4-3. Propagation Loss Over Complex Terrain.

P. Beckman and A. Spizzichino, The Scattering of Electromagnetic Waves from Rough Surfaces, MacMillan Co. , 1963.

H. F. Schmid, "A Prediction Model for Multipath Propagation of Pulse Signals at VHF and UHF Over Irregular Terrain",IEEE Trans. on Antennas and Propag., vol. AP-12, no.2, March 1970, pp. 624-635.

H. Jasik, Antenna Engineering Handbook, New York, McGraw-Hill, 1961.

J.J. Egli, "Radio Propagation Above 40 Mc over Irregular Terrain," Proc. IRE, vol. 45, pp. 1383-1391, October 1957.

ECAC-TTP, Release 3, EMC Program, Department of Defense, Electromagnetic Compatibility Analysis Center, Annapolis, Maryland.

4.1.2.5 Proposed Testing and Verification. Basically, our work can be validated through :

1. in flight measurements at NATC or elsewhere,
2. comparison with available Published experimental data, and
3. laboratory experiments for some simple cases.

4.1.3 Propagation Effects

Propagation phenomena such as absorption, scattering, scintillation, ducting depolarization, dust and sand, and multipath fading affect the characteristics of an electromagnetic wave, as shown in Figure 4-4. Many of these phenomena can be present on the transmission path at the same time and it is usually extremely difficult to identify the mechanism or phenomena which produce a change in the characteristics of the transmitted signal. This situation is illustrated in Figure 4-5, which indicates how the various propagation mechanisms affect the measurable parameters of a signal. The parameters that can be observed or measured are amplitude, phase, polarization, frequency, bandwidth and angle of arrival. Each of the propagation mechanisms, if present in the path, will affect one or more of the wave parameters, as shown in Figure 4-5. For example, a reduction of amplitude caused by rain is the result of absorption and scattering.

The major propagation factors that can affect the behavior of the electromagnetic wave are:

Atmospheric Absorption
Tropospheric/Ionospheric Scintillation
Ducting

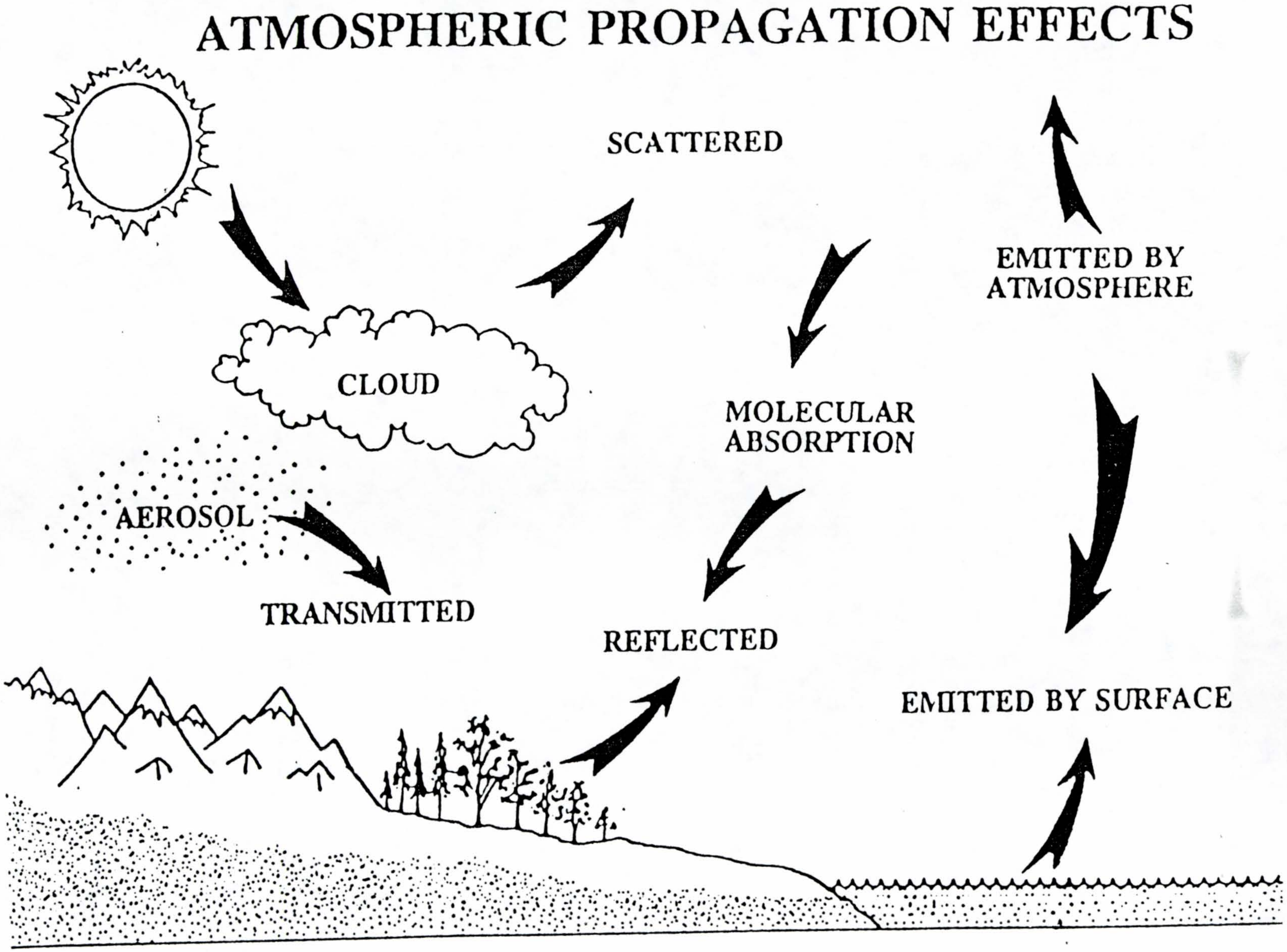


Figure 4-4. Atmospheric Propagation Effects.

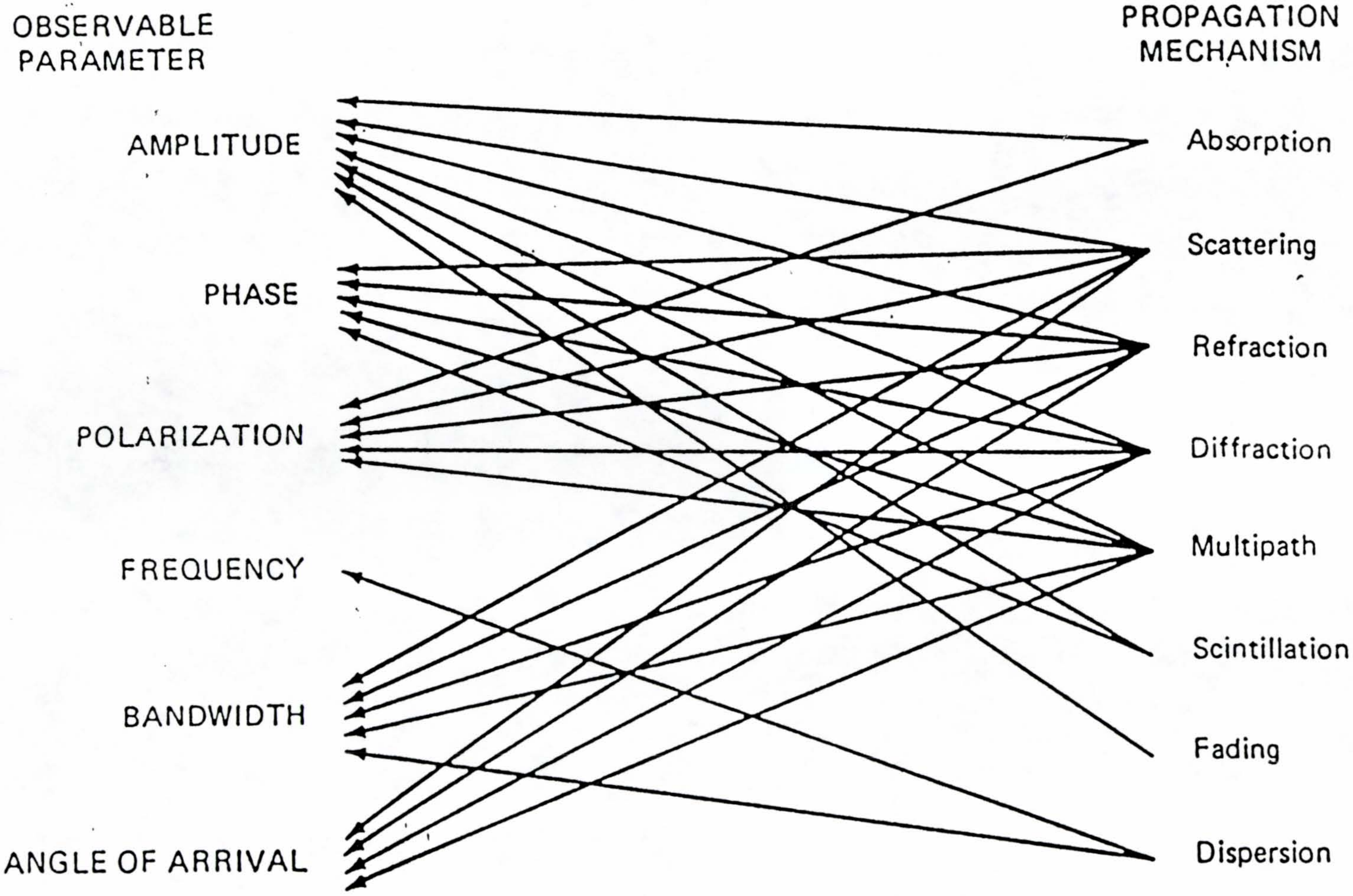


Figure 4-5. Effects of Propagation Mechanisms on Signal.

4.1.3.1 Atmospheric Attenuation. The presence of rain, fog, cloud, hail, ice or snow in the propagation path can modify the transmitted signal and cause major impairments to the communication system as a whole. Rain drops absorb and scatter the electromagnetic wave, resulting in signal attenuation. Hail, ice and snow play a minor role in producing attenuation of the signal as compared to rain, clouds and fog.

The attenuation of a wave propagating in a volume of rain of extent L is the direction of propagation is expressed as

$$A = \int_0^L \alpha \, dx \, . \qquad 1$$

For a plane wave of transmitted power P_t incident on a volume of uniformly distributed spherical water drops, or radius r, extending over a length L, the received power P_r is

$$P_r = e^{-kL}$$

where k is the attenuation coefficient for the rain volume in units of reciprocal length.

The attenuation of the wave, is given by

$$A = 10 \log_{10} \frac{P_t}{P_r} \qquad db$$

using (1),

$$A = 4.343 \, kL \qquad db$$

The attenuation coefficient is expressed as

$$k = \rho \, Q_t$$

where ρ is the drop density, i.e., the number of drops per unit volume and Q_t is the attenuation cross section. Q_t is a function of the drop radius, r, the wavelength λ, of the wave and the complex refractive index of the water drop, m. That is

$$Q_t(r, \lambda, m) = Q_s + Q_a$$

Q_s is the scattering cross section and Q_a is the absorption cross section. In general the attenuation coefficient can be expressed as

$$k = \int Q_t(r,\lambda,m)\, n(r)\, dr$$

where n(r) is the drop size distribution. The specific attenuation is db/km is

$$\alpha = 4.343 \int Q_r(r,\lambda,m)\, n(r)\, dr$$

The above result demonstrates the dependence of rain attenuation on drop size, drop size distribution, rain rate and attenuation cross section. The first three parameters are characteristics of the rain structure only. It is through the attenuation cross section that the frequency and temperature dependance of rain attenuation is determined. All of the parameters exhibit time and spatial variations which are random in nature and hence predictions of rain attenuations must depend on statistical methods of analysis.

The distribution of rain drop size as a function of the rain rate and type of storm activity can be represented by an exponential of the form

$$n(r) = N_0\, e^{-br} = N_0\, e^{-cR^{-d}}\, dr$$

where R is the rain rate in mm/hr and r is the drop radius. N_0,b,c and d are empirical constants determined from measured distributions.

The specific attenuation can now be expressed as

$$\alpha = 4.343 N_0 \int Q_t(r,\lambda,m)\, e^{-br} dr \quad db/km$$

The total rain attenuation over a given path L is then given by

$$A = 4.343 \int_0^L \left[N_0 \int Q_t e^{-br} dr \right] dx \quad db$$

The specific attenuation produced on the wave path can be approximated by

$$\alpha = aR^b \qquad db/km$$

where a and b are frequency and temperature dependent constants.

4.1.3.1.1 **Models for Rain Attenuation Prediction.** Almost all prediction models use surface measured rain rate as the statistical variable and assume the aR^b relationship to determine the rain attenuation. The prediction models can be expressed in the form

$$A(db) = aR^b L(R)$$

where L(r) is an effective path length parameter.

Rice-Holmberg Model
This model constructs a rain rate distribution by assuming that the rain structure can be divided into two types - thunderstorm rain and all other rain. The sum of these two modes produces the total distribution.

Dutton-Dougherty Model
This model is based on meteorological considerations of the propagation path. It provides atmospheric attenuation, i.e., gaseous, cloud and rain attenuation. The model has been updated to provide a more flexible procedure for general use.

CCIR Rain Attenuation Model
This model determines an annual attenuation distribution at a specified location from an average year rain rate distribution. It employs three separate methods for maritime climates, continental climates, and tropical climates.

4.1.3.2 Tropospheric/Ionospheric Scintillation. Scintillation is the rapid fluctuation of the signal parameters caused by time-dependent irregularities in the path of the wave. The amplitude, phase, polarization and angle of arrival of the wave are affected by scintillations. Scintillation effects are produced in the troposphere and in the ionosphere, however, the mechanisms and characteristics for each differ.

Ionospheric scintillations, produced by electron density fluctuations approximately 200-400 km in altitude, are prevalent in the equatorial regions and high latitude locations. A detailed analytical procedure to predict the ionospheric scintillations is difficult to attain. Approximate solutions of the wave propagation model for a volume of random refractive index irregularities for specialized conditions are available.

Tropospheric scintillation is produced by refractive index fluctuations in the first few kilometers of altitude and is caused by high humidity gradients. The effects are dependent on the seasons and vary with the local climate. The tropospheric scintillations can, as a first approximation, be considered as being horizontally stratified with the refractive index of the thin layers changing with altitude.

4.1.3.2.1 **Available Models.** A number of models are available to investigate propagation effects. The models identified below can achieve about 70% of the research objectives for TESTS. Further research is needed to arrive at more detailed models especially for the S and X bands.

Ionospheric Scintillation

Born Approximation	Weak scintillation produced by a thin region or a single dominant irregularity
Rytov Approximation	Weak scintillation and a thick irregularity region
Single Thin Phase Screen	Strong scintillation and a thin layer
Markov Approximation	Strong scintillation and a thick layer

Tropospheric Scintillation
ECAC Software Package

EREPS: Refractive Effects Prediction System
Developed by the Naval Ocean Systems Center Tropospheric Branch, Ocean and Atmospheric Sciences Division. This package can accurately predict the propagation of refraction and tropospheric scatter.

CCIR Tropospheric Scintillation Model

4.1.3.3 <u>Atmospheric Ducting</u>. The propagation of electromagnetic waves is affected by the earth's surface and its atmosphere. Electromagnetic waves traveling within the earth's atmosphere do not travel in straight lines, but are bent or refracted. The effect of this refraction is to increase the distance to the horizon or to increase the radar range, as shown in Figure 4-6, and to introduce errors in the measurement of the elevation angle. The downward bending of the waves is caused by the decrease in the index of refraction with altitude which causes an increase in the velocity of propagation of the wave. This phenomena, shown in Figure 4-7, is referred to as superrefraction, ducting or trapping. A duct which lies close to the ground is called a ground or surface duct, while a duct that lies above the surface is called an elevated duct. To propagate energy within an elevated duct, the angle the wave makes with the duct direction, defined by the levels of constant index of refraction, should be less than one degree. Atmospheric ducts are generally of the order of 10 or 20 meters in height, and never more that 150 to 200 meters.

Ducting, Figure 4-7, can occur under various circumstances. For the index of refraction to decrease with height, the temperature must increase or the humidity must decrease with height. This is referred to as a temperature inversion and occurs when the temperature of the sea or land surface is appreciably less than

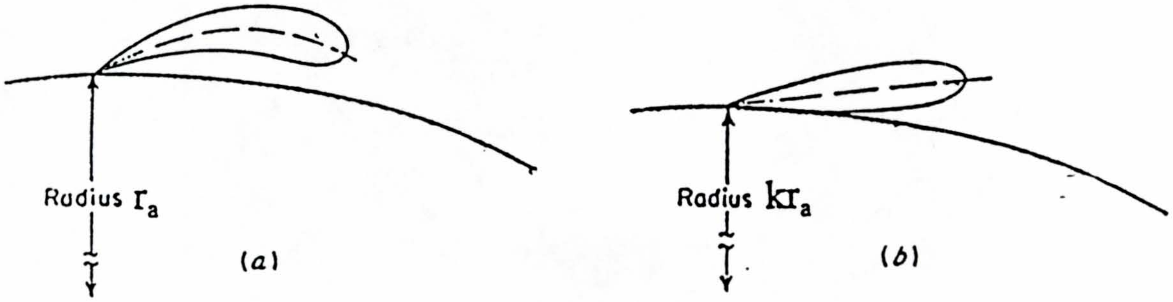


Figure 4-6. Effect of Refraction on Antenna Beam.

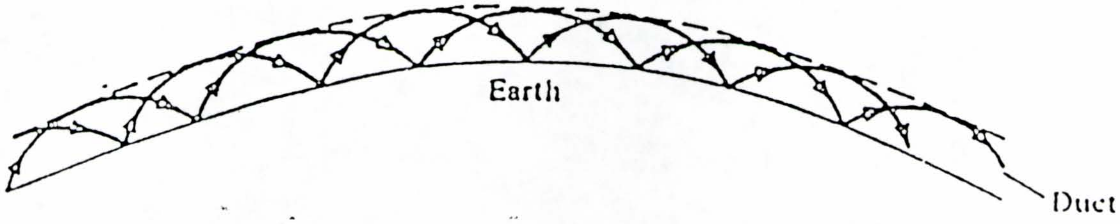


Figure 4-7. Illustration of Ducting.

that of the air. Ducting also occurs when the upper air is exceptionally warm and dry in comparison with the air at the surface, or due to the movement of warm dry air from land over cooler bodies of water.

When propagating within the duct, the extension of the radar range results in a reduction of coverage in other directions. The regions with reduced coverage are called radar holes. Due to the presence of a surface duct, targets just above the duct that would normally be detected would be missed, as shown in Figure 4-8. On the other hand, an evaporation duct (over the sea or an ocean), when used with a properly sited antenna, can provide considerably extended coverage against surface targets or low flying targets. These target normally may not be detected in the absence of the duct. Distances up to approximately 3200 km are possible through ducting. However, the presence of the extended range cannot always be predicted in advance. Generally, the consequence of the presence of the duct is more negative than positive.

The variation of refraction with height can be modeled in a linear or exponential form. At microwave frequencies, the linear model is used.

$$N = (n - 1)\,10^6 = 77.6\frac{P}{T} + 3.373 \times 10^5 \frac{e}{T^2}$$

where P = barometric pressure, mbar (1mm = 1.3332 mbar)
e = partial pressure of water vapor, mbar

T = absolute temperature, K
N = the refractivity, the "scale up" index of refraction.

The index of refraction of the earth's surface is 1.0003 and in a standard atmosphere. the index decrease at the rate of about 4E-10 m^{-1} of height.

For purposes of computation, the atmospheric refraction is accounted for by a factor k. This factor k, when multiplied by the actual radius r_a of the earth, will yield the effective radius r_e ($r_e = k\, r_a$). Then the actual atmosphere is replaced by a homogeneous atmosphere where the waves will travel in straight lines rather than curved lines, as shown in Figure 4-9. The value for k can then be written as

$$k = \frac{1}{1 + r_a\left(\frac{dn}{dh}\right)}$$

= rate of change of the earth's atmospheric refractive index n with altitude h above the earth's surface. Usually is less than 0 where r_a is the actual radius of the earth.

This standard refraction is used when the index of refraction decreases uniformly with altitude so that k = 3/4.

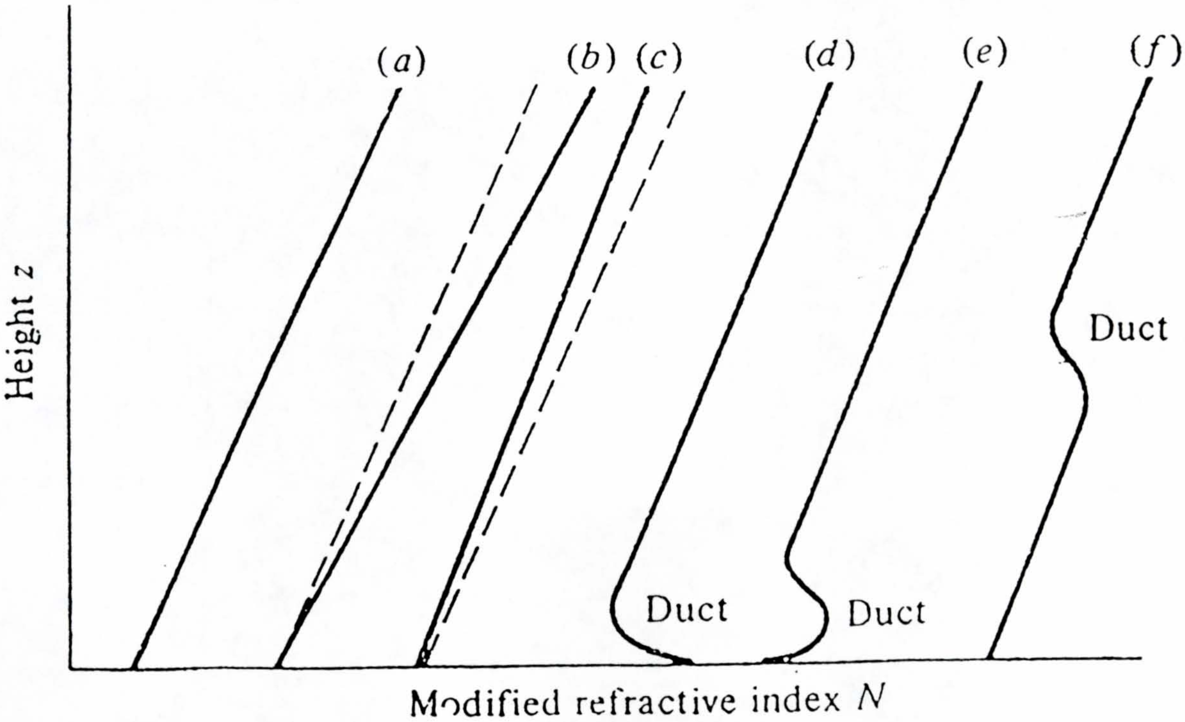


Figure 4-8 Modified Index of Refraction Profiles.

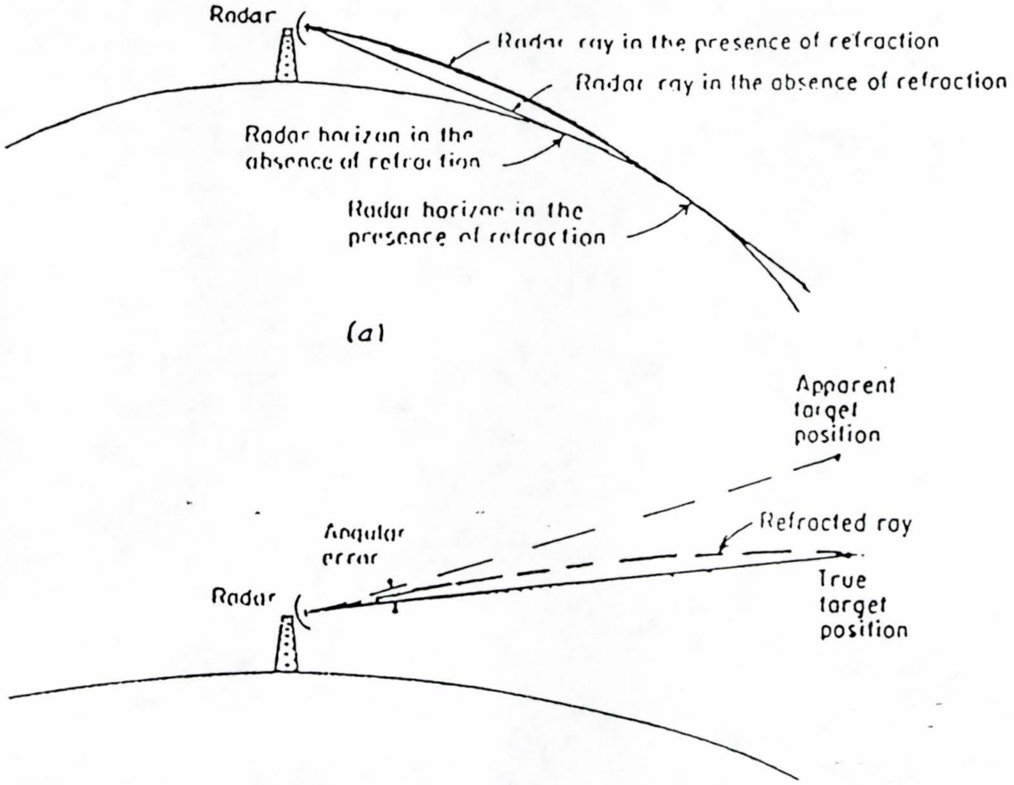


Figure 4-9 Effect of Ducting on Radar Detection.

The horizontal distance from the radar at a height h is calculated as

$$d = \sqrt{2kr_a h}$$

for k = 3/4

$$d = \sqrt{2h(ft)} \qquad statue\,miles$$

$$d = 1.23\sqrt{h(ft)} \qquad nautical\,miles$$

$$d = 130\sqrt{h(km)} \qquad km$$

The use of r_e in the linear model implies that n decreases linearly with height. However, for heights above 1 km, the experimental results are in disagreement with the linear model. A more accurate model is one in which the refractivity varies exponentially with height

$$N = N_s \exp(-C_e(h_t - h_r))$$

where N_s = refractivity at the surface of the earth
h_t = altitude of the target

h_r = altitude of the radar
$C_e = \ln(N_s/N_1)$ = constant depending on N_s and N_1, the refractivity at an altitude of 1 km.

A simplified model of propagation in the atmospheric ducts gives the maximum wavelength that can be propagated in a surface duct as

$$\lambda_{max} = 2.5\left(-\frac{\Delta n}{\Delta h}\right)^{\frac{1}{2}} d^{\frac{3}{2}}$$

where d = depth of the surface duct
Δh = altitude above the ground
λ_{max} , d, Δh have the same units.

4.2 COMMUNICATIONS RESEARCH STUDIES

This report summarizes the efforts on the TESTS research program by the communications group. The COM group consisted of Dr. Belkerdid, Dr. Georgiopoulos, and Mr. Koller. The report covers the research effort during fall 90 and spring 91. Most of fall 1990 was spent on understanding the problems and issues regarding the MARK XII and MARK XV IFF systems. There were biweekly reports issued regarding detail studies pertaining to subsystems of the above mentioned systems. In particular, various mode formats were studied and analyzed. The interest was all the way to the basic baseband pulse characteristics, modulation schemes and basic transmitted waveforms.

A literature search was performed in the fall semester as well. Topics included all aspects of the basic components of interrogators as well as transponders. Mode/format generators, encryptors, forward error correction encoders/decoders, as well as various spreading mechanisms were items of interest among others.

A SUN workstation was purchased, and the SPW, BOSS software was acquired and installed. The unique capability is now operating and the system will be used as a design, analysis, simulation, and verification for the TESTS research program.

The study of Code Division Multiple Access (CDMA) was undertaken during the Spring 91 semester. Multiplexers interference is of prime interest to an IFF system, as they act as undesirable jammers, and limit the system capacity. The spreading mechanisms, with the MARK XV as a target application, were extensively studied. Multipath interference was also studied, and the study of a stochastic multipath model was performed.

The SPW (BOSS) simulator is an effective tool for modeling entire or partial communication systems. It has an open-ended architecture that allows construction of transceivers, signal values can be traced throughout the system. At any block location and at any level sink files can be placed to retrieve signal information. These sink files can then be used to calculate system performance parameters and system performance parameter sensitivity. Signal to noise ratio, Probability of error, system capacity, and parameter sensitivity are important fundamental communication system performance parameters that need to be performed before hardware systems are acquired.

Since the highest risk of the TESTS program is in the environmental simulation hardware tool, it is proposed that BOSS be used as a simulator for the environmental signal conditioning. If phase shifters , attenuators, amplifiers, and other hardware RF processors are used, Boss can simulate their effects prior to their acquisition. Boss can also model channel effects such as multipath and fading.

4.2.1 System Simulation Examples Using BOSS

Preliminary studies showed that BOSS is a viable tool for simulation of spread spectrum signals such as MARK XV waveforms. BOSS is not a spread spectrum signal simulator, but it can easily be adapted to generate both single and multiple spread spectrum signals pertaining to an IFF system. BOSS can also simulate a complete transceiver because of its modularity. Enclosed are sample systems that were simulated using BOSS.

The first one consists of a Direct Sequence Spread Spectrum modulator, with sink files at every level, such that signals at various points on the system can be analyzed both in the time and frequency domains. Figure 1 illustrate a direct sequence spread spectrum generator in the presence of a CW jammer and an Additive White Gaussian Noise (AWGN) source. Signals can be view at any point of the system both in the time and frequency domain by using the signal processing capabilities of BOSS.

Figure 2 illustrates the spectra of the spread spectrum waveform and the CW jammer described in Figure 1. Every parameter of the system shown in Figure 1 is user definable and the system can represent a MARK IV or MARK XV with minor modifications.

The PN generator is shown in Figure 3. The primitive polynomial, which automatically fixes the sequence length and the coded feedback connections in the shift register configuration, and the shift register initial conditions are user definable. This capability makes BOSS a viable tool for the TESTS program.

Figure 4 shows a multiple PN sequence generator. It is based on some properties of PN sequences and is of primary importance in generating multiple spread spectrum waveforms and in the simulation of multiple access interference, which is a limiting factor in system capacity.

BOSS can also perform encryptions, Figure 5 shows a scrambler/descrambler system. The data S1, shown in Figure 6, is encrypted and the scrambled data is denoted by S2, the AUX signal in Figure 6 is the output of the descrambler.

BOSS has some of the basic modules for generic receivers. Figure 7 depicts a PSK matched filter receiver, Figure 8 depicts an Integrate and Dump receiver, Figure 9 shows an envelope detector, while Figure 10 illustrates an FM transceiver using both PLL and discriminator type of demodulator.

BCH, Reed-Solomon and Convolutional coding/decoding are examples of data encoding BOSS is capable of performing. Figure 11 illustrates a BCH encoder/decoder. The error correction capability is again user definable. S1, shown in Figure 12, is the data input to the encoder, S2 is the encoder output, S3 is the decoder input with errors, while S4 is the decoded output with errors corrected. Figures 13 and 14 depict a Reed-Solomon encoder/decoder and the signal waveforms respectively.

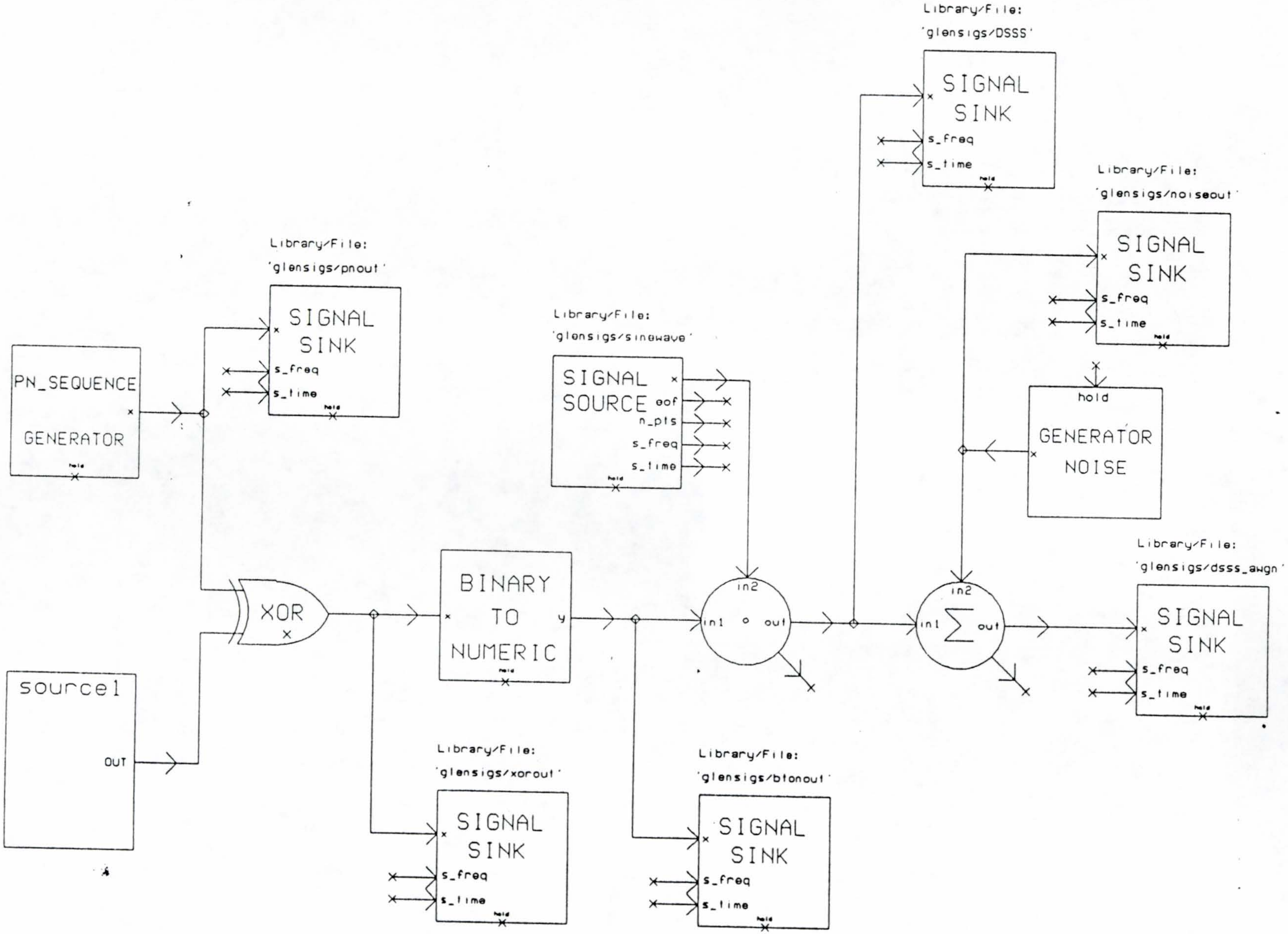


Figure 4-10. Direct Sequence Spread Spectrum Generator.

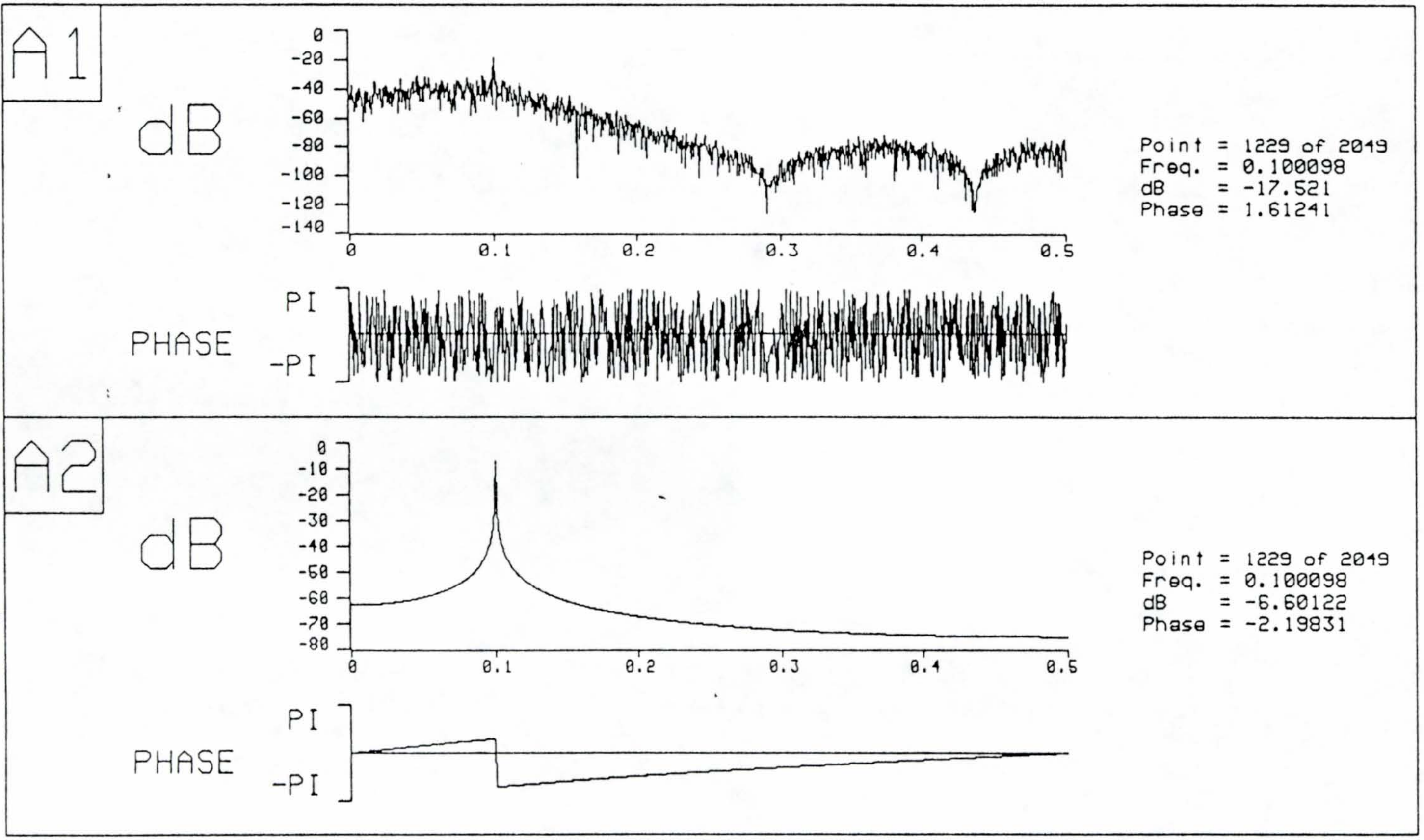


Figure 4-11. Spectra of the Spread Spectrum Waveform.

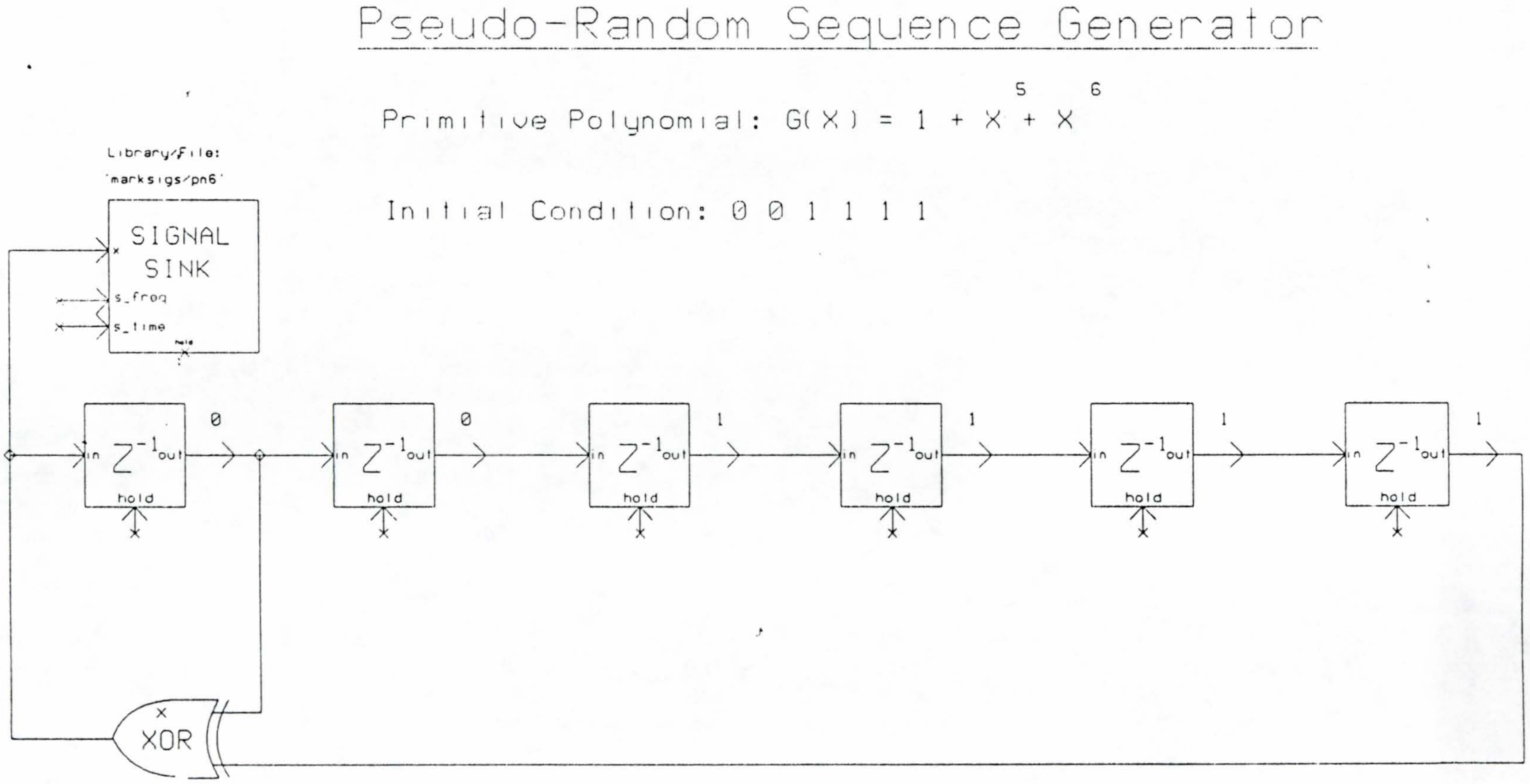


Figure 4-12. PN Generator.

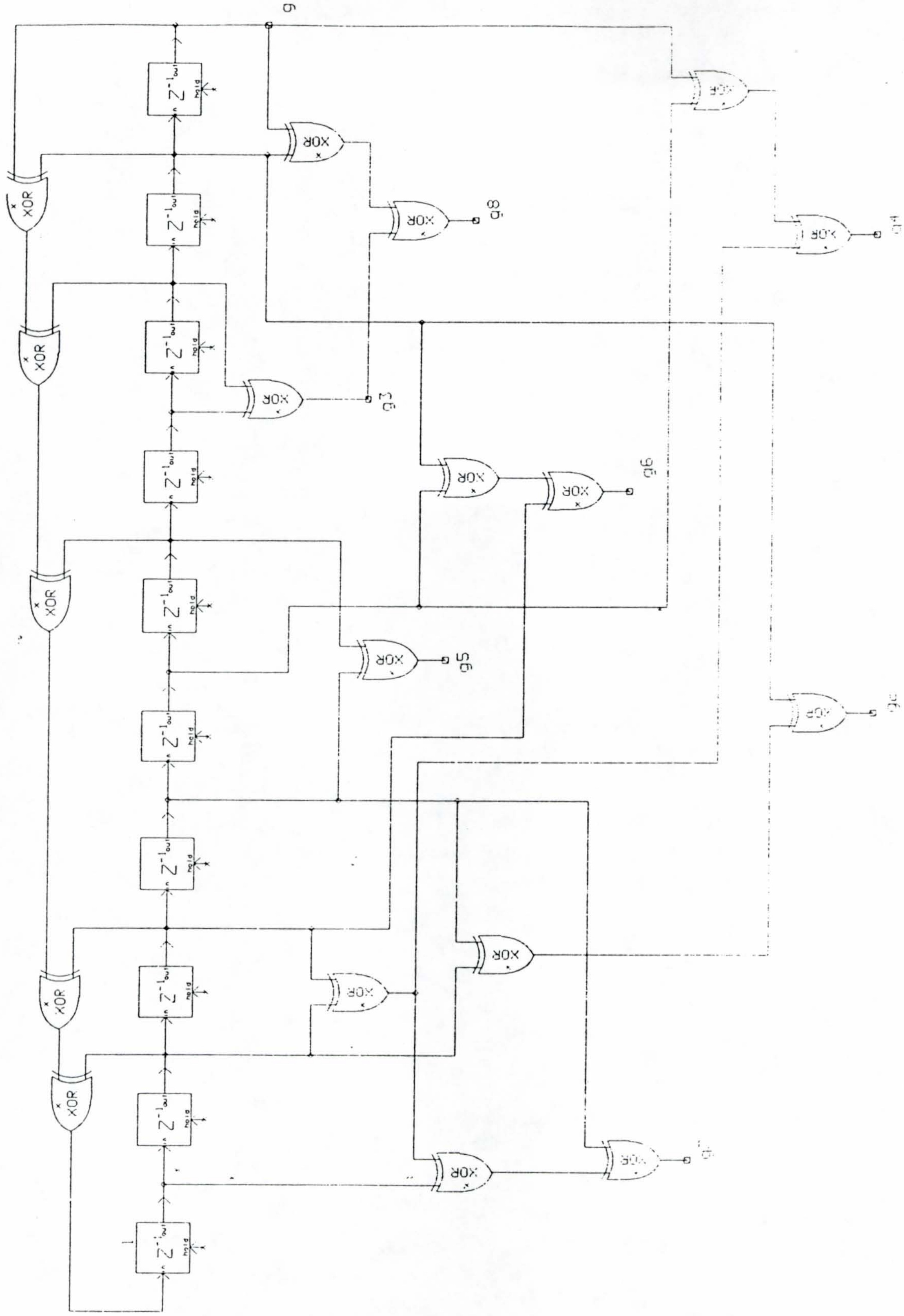


Figure 4-13. Multiple PN Sequence Generator.

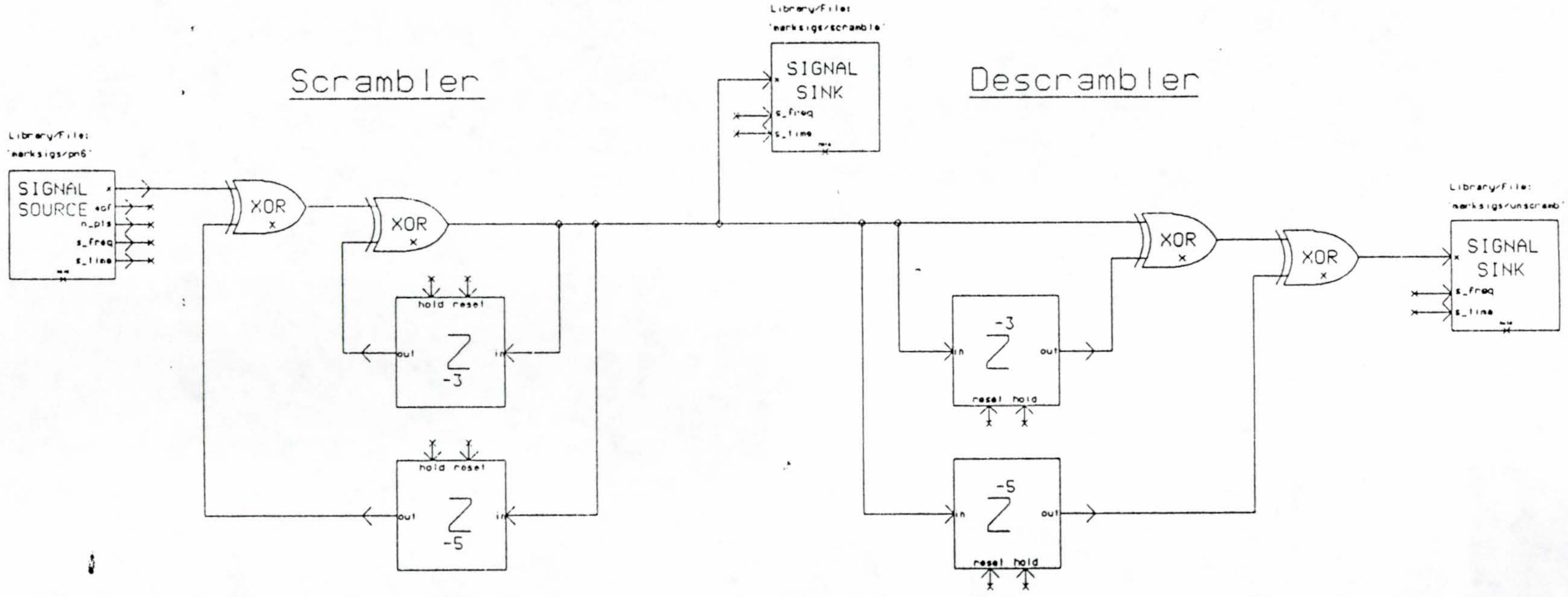
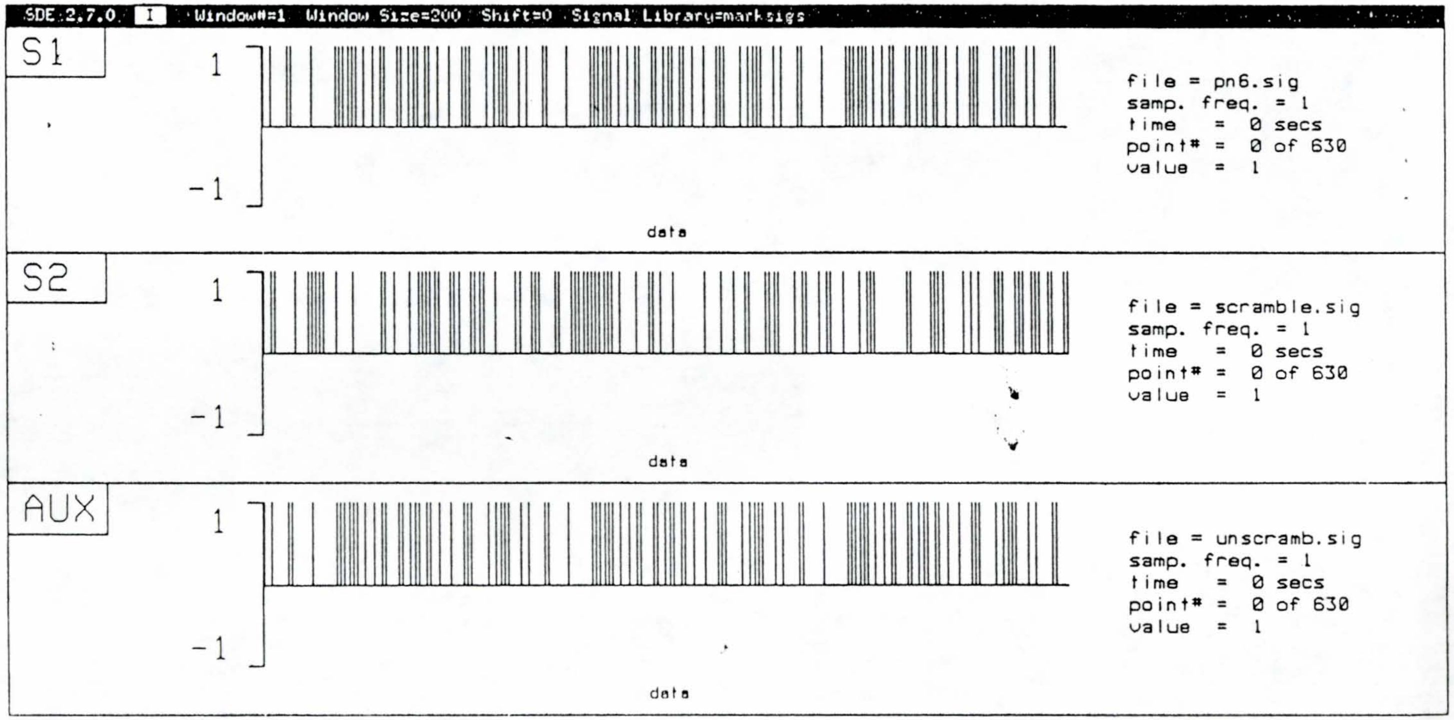


Figure 4-14. Scrambler/Descrambler System.



```
SDE 2.7.0  I  Window#=1  Window Size=200  Shift=0  Signal Library=marksigs

file = pn6.sig
samp. freq. = 1
time    =  0 secs
point# =  0 of 630
value   =  1

file = scramble.sig
samp. freq. = 1
time    =  0 secs
point# =  0 of 630
value   =  1

file = unscramb.sig
samp. freq. = 1
time    =  0 secs
point# =  0 of 630
value   =  1
```

Figure 4-15. Sample Data.

PSK MATCHED_FILTER DEMODULATOR BLOCK PARAMETERS

MAIN PARAMETERS:

PSK constellation first angle (Deg.)	45.0
PSK modulation order	4.0
Baud rate	1.0
Time delay to input (Sec.)	0.0
Channel phase rotation (Deg.)	0.0
Sampling frequency	16.0

MISCELLANEOUS PARAMETERS:

Initial value	0.0
Overflow value	0.0
Error count before action	1
Action taken (stop or continue)	'stop'

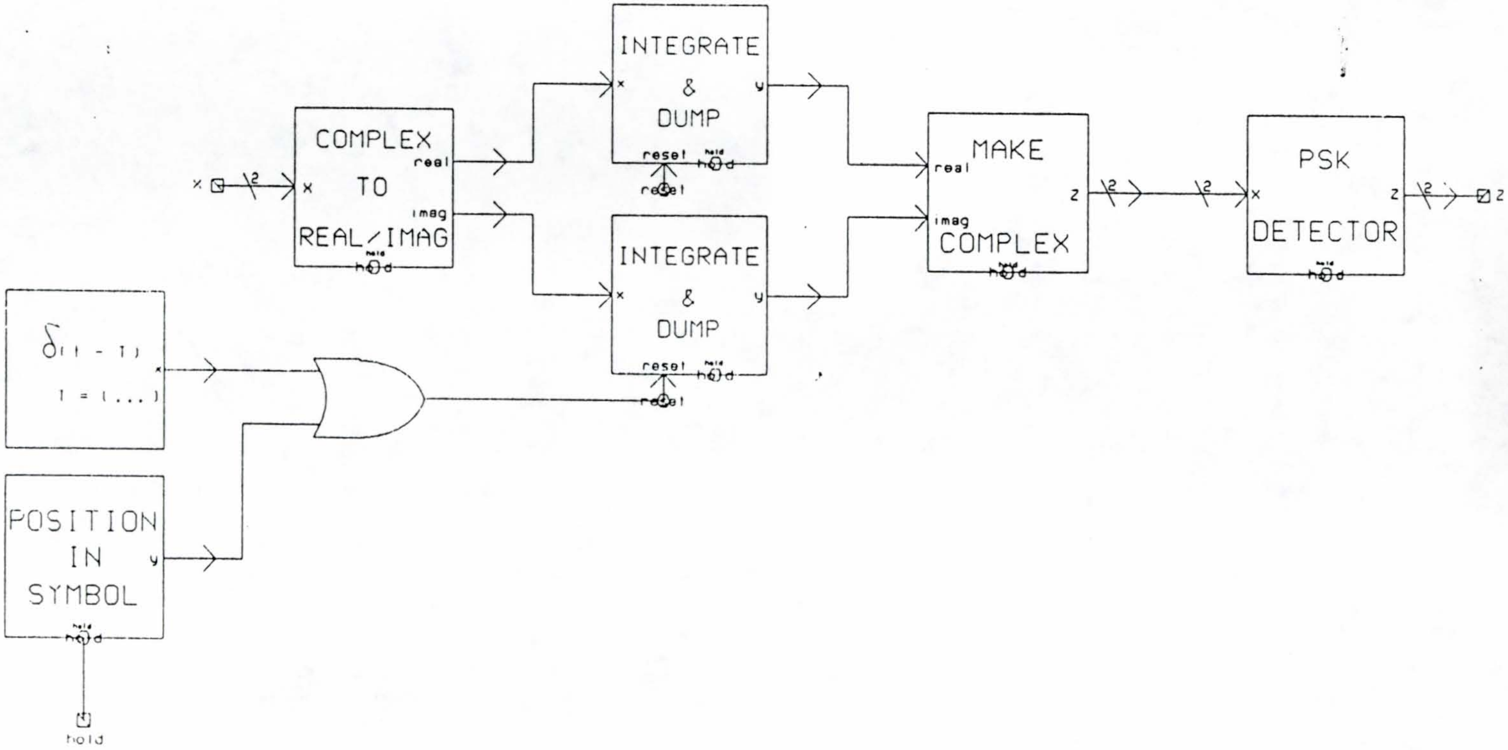


Figure 4-16. PSK Matched Filter Receiver.

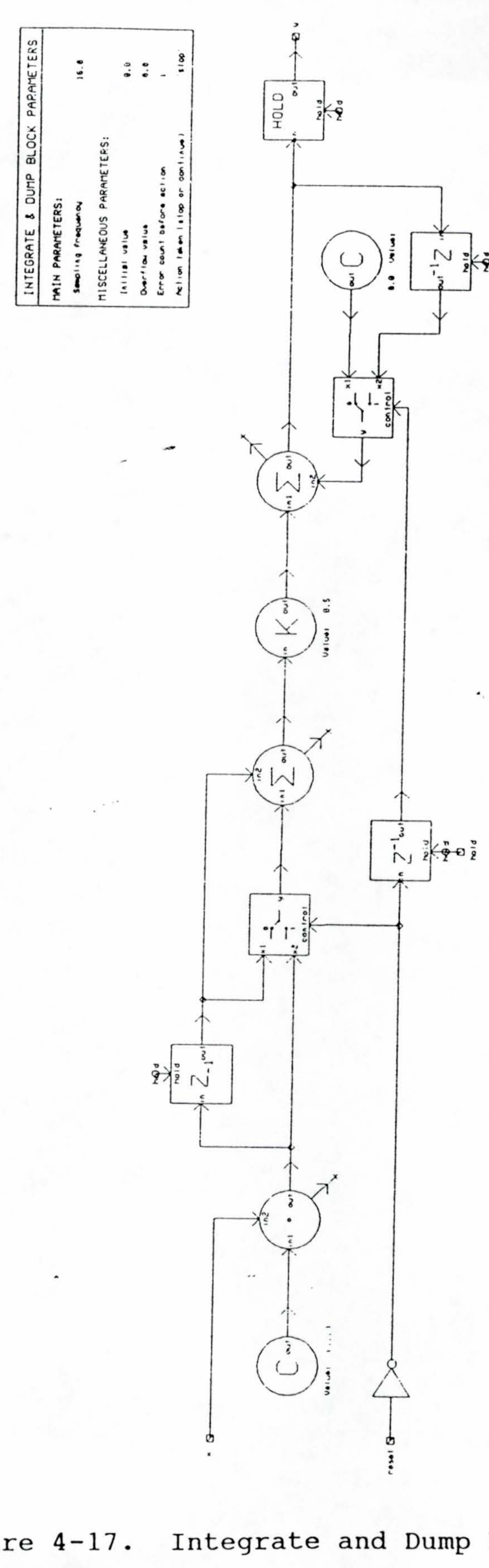


Figure 4-17. Integrate and Dump Receiver.

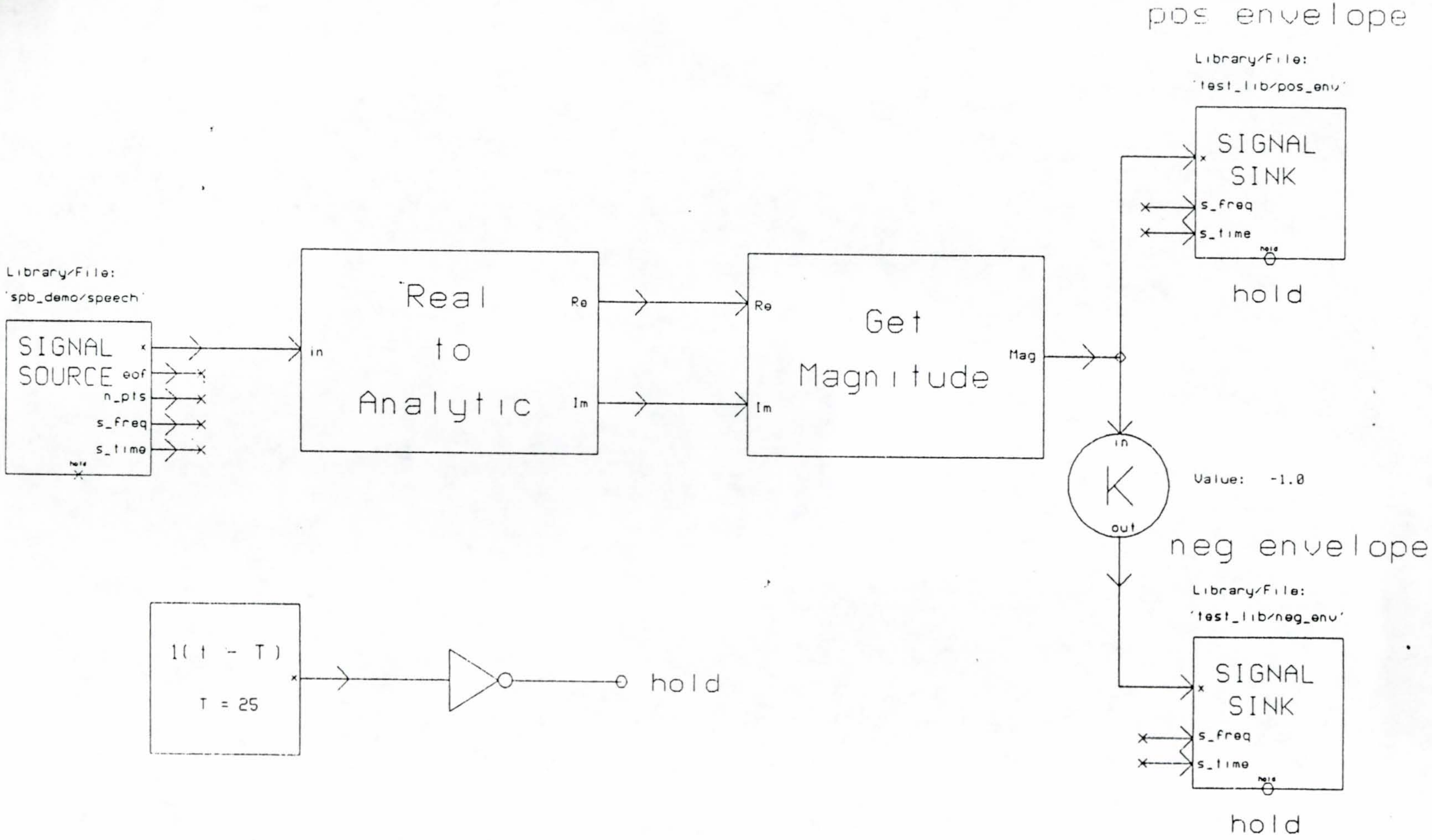


Figure 4-18. Envelope Detector.

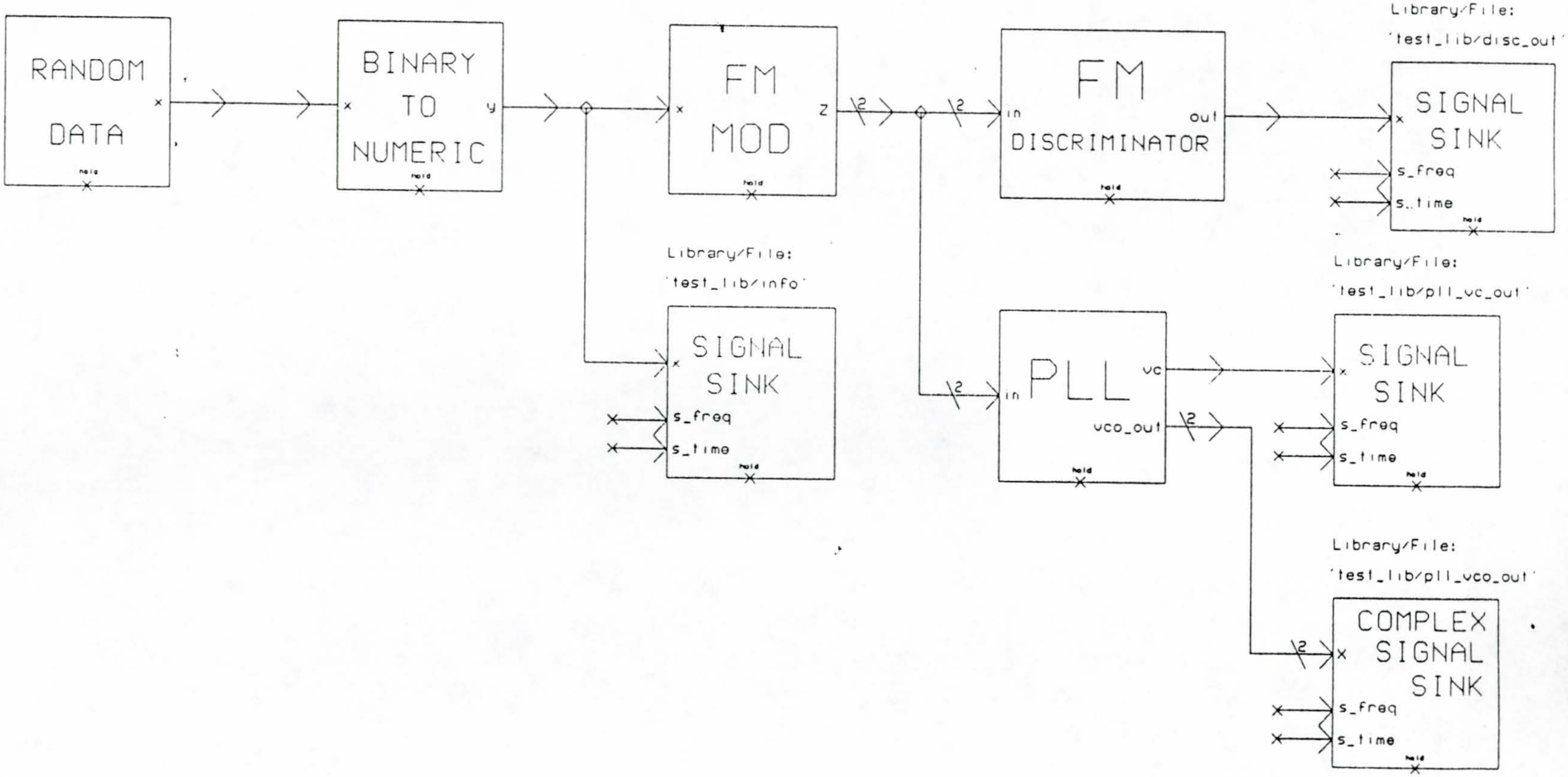
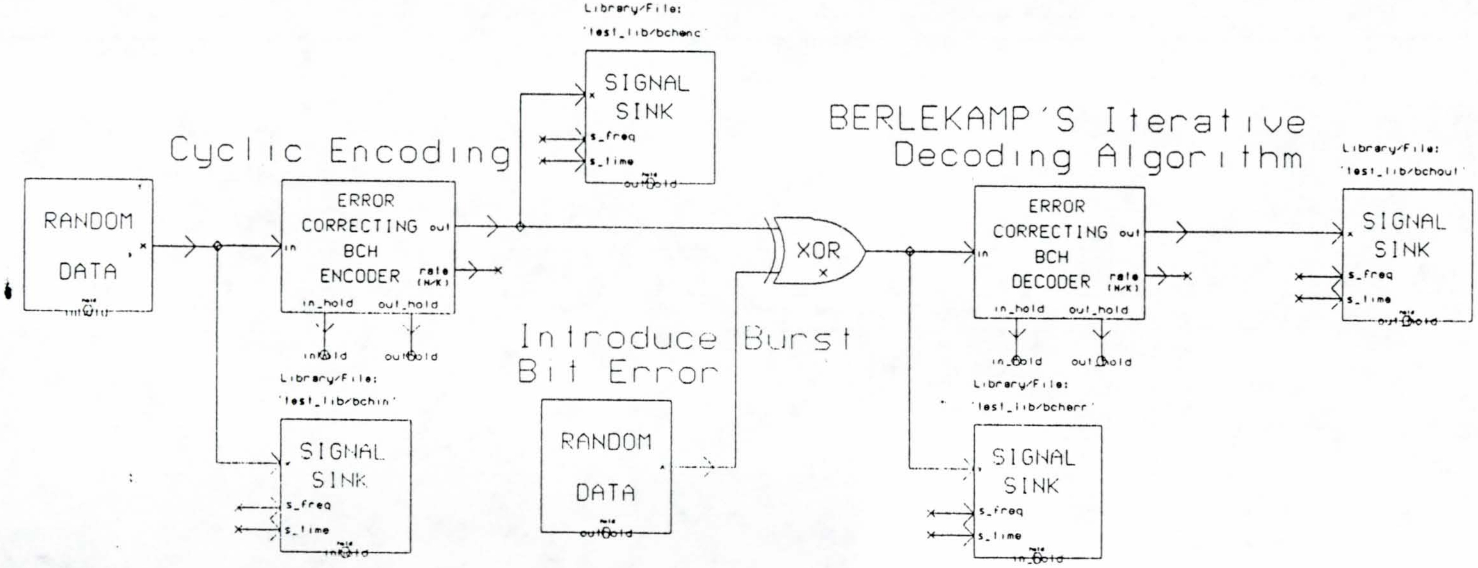


Figure 4-19. FM Transceiver.



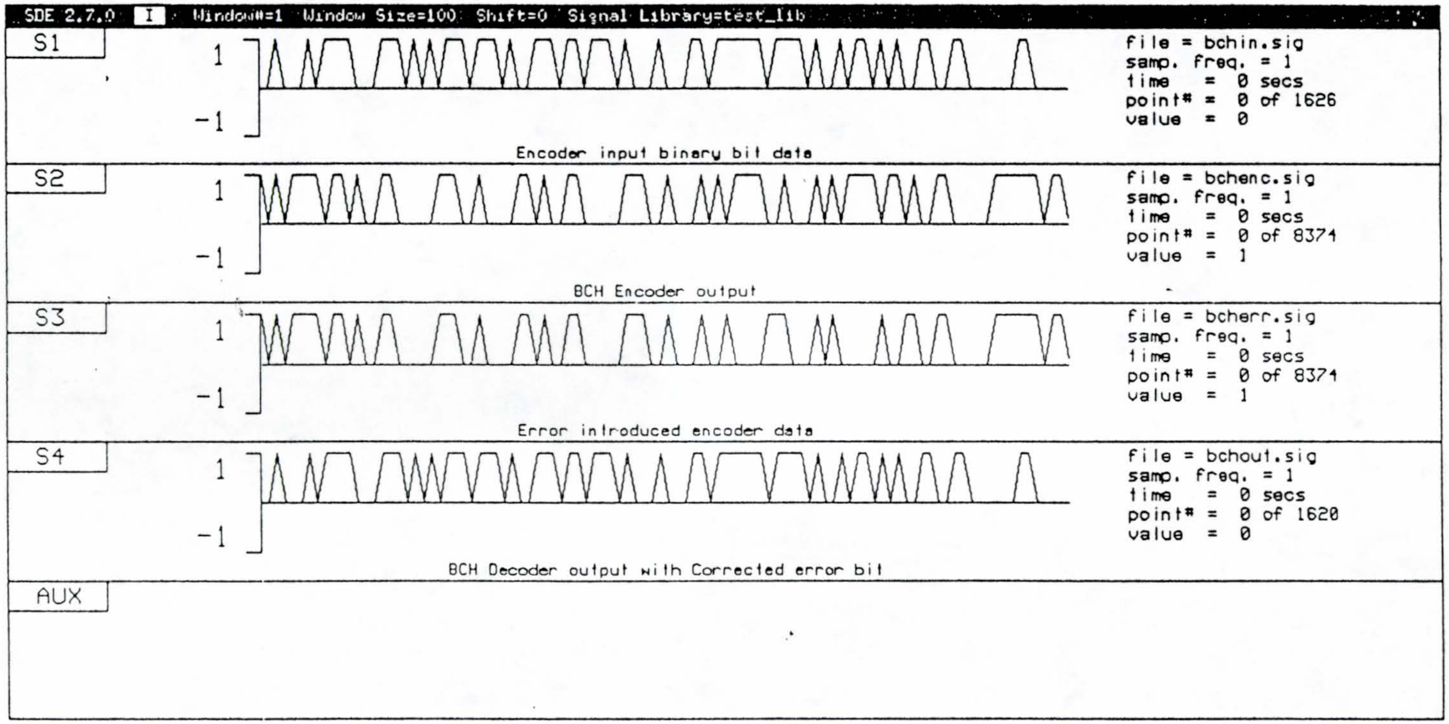
By Default, this system is G(31,6) 6 error correcting code system.

For G(n,k) t error correcting system:

Block Length: $n = 2^m - 1$
Number of parity-check bits: $n - k <= mt$
Minimum distance: $d_{min} >= 2t + 1$

n	k	t	n	k	t
7	4	1	63	57	1
15	11	1		51	2
	7	2		45	3
	5	3		39	4
31	26	1		36	5
	21	2		30	6
	16	3		24	7
	11	5		18	10
	6	7		16	11
				10	13
				7	15

Figure 4-20. BCH Encoder/Decoder.



```
SDE 2.7.0  I  Window#=1  Window Size=100  Shift=0  Signal Library=test_lib

S1                                              file = bchin.sig
                                                samp. freq. = 1
                                                time   =  0 secs
                                                point# =  0 of 1626
                                                value  =  0
              Encoder input binary bit data

S2                                              file = bchenc.sig
                                                samp. freq. = 1
                                                time   =  0 secs
                                                point# =  0 of 8374
                                                value  =  1
                 BCH Encoder output

S3                                              file = bcherr.sig
                                                samp. freq. = 1
                                                time   =  0 secs
                                                point# =  0 of 8374
                                                value  =  1
             Error introduced encoder data

S4                                              file = bchout.sig
                                                samp. freq. = 1
                                                time   =  0 secs
                                                point# =  0 of 1620
                                                value  =  0
       BCH Decoder output with Corrected error bit

AUX
```

Figure 4-21. Sample Data.

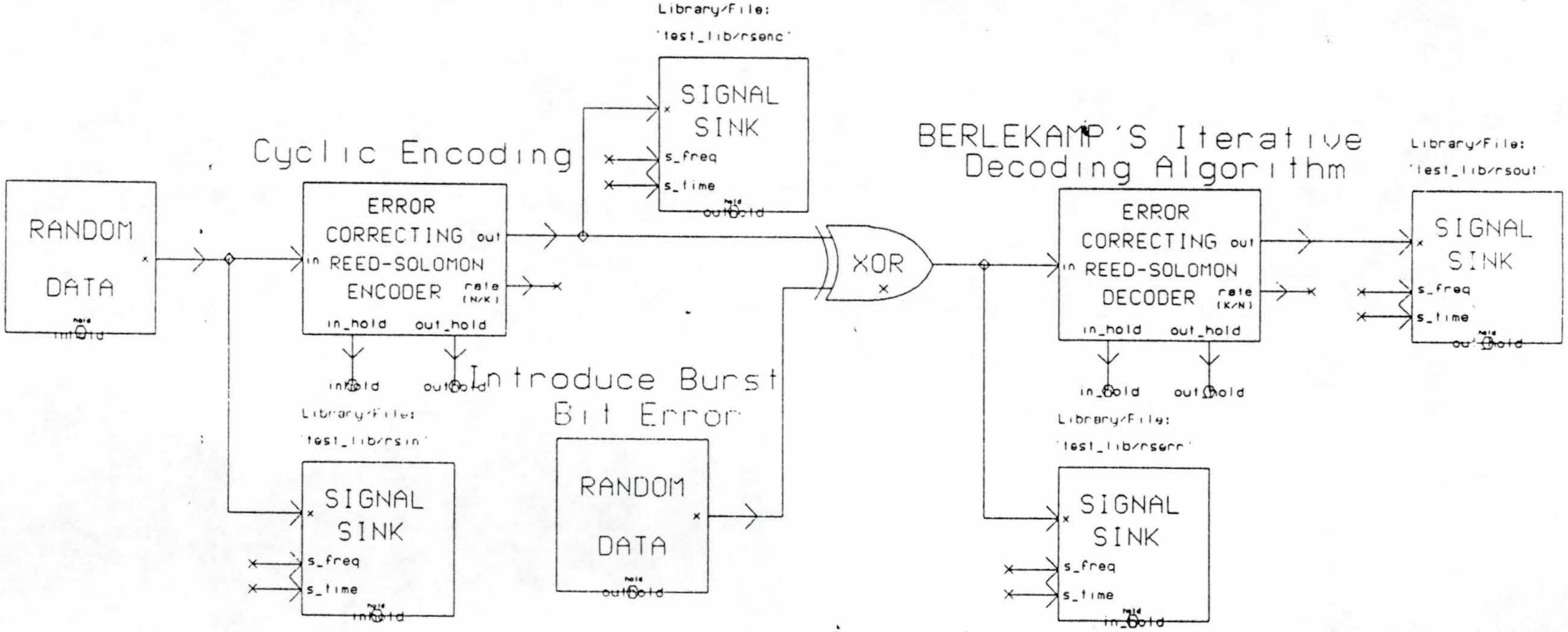


Figure 4-22. Reed-Soloman Encoder/Decoder.

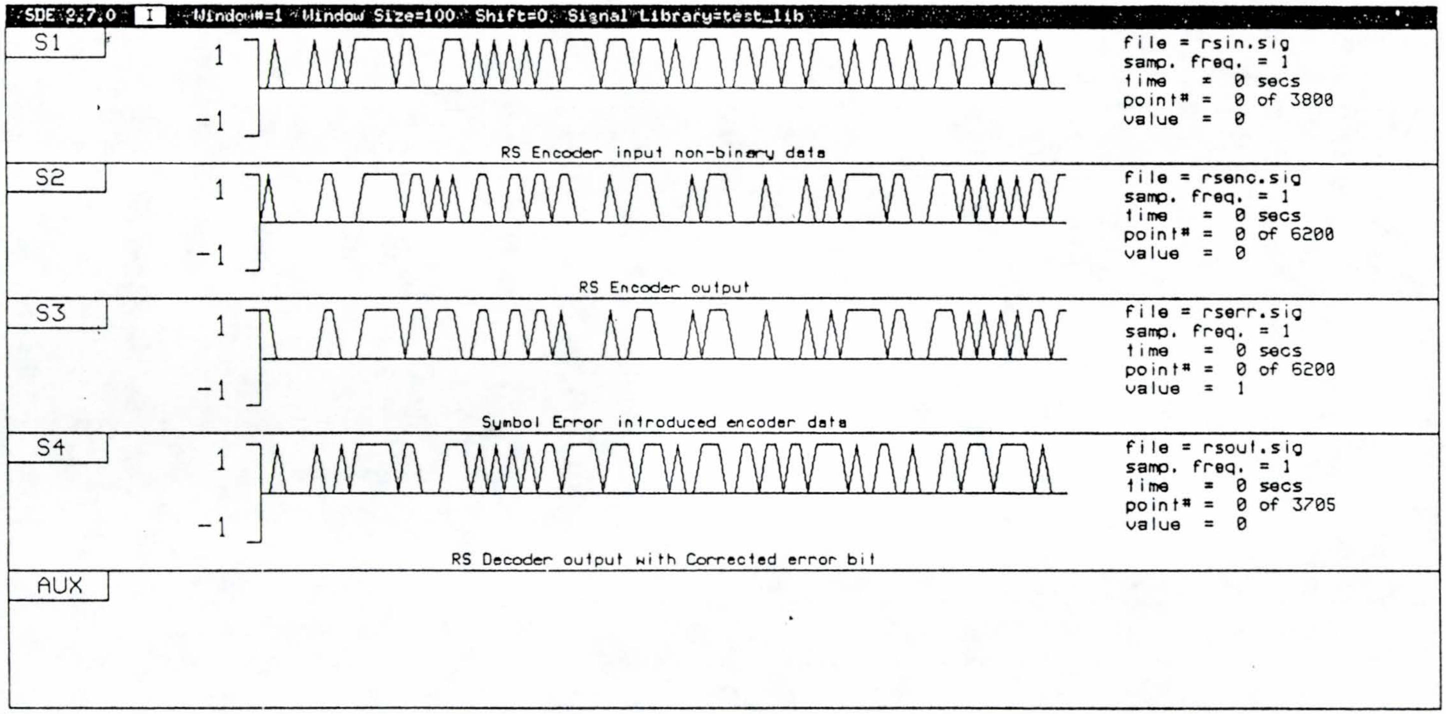
By Default, this system is G(31,19) 6 error correcting RS code system.

For $G(q)$ ($q = 2^m$) t error correcting code system:

Code Block Size: $n = q - 1$

Number of parity-check symbols: $n - k = 2t$

Minimum distance: $d_{min} = 2t + 1$



```
SDE 2.7.0  I  Window#=1 Window Size=100 Shift=0 Signal Library=test_lib

file = rsin.sig
samp. freq. = 1
time    =  0 secs
point# =  0 of 3800
value   =  0
RS Encoder input non-binary data

file = rsenc.sig
samp. freq. = 1
time    =  0 secs
point# =  0 of 6200
value   =  0
RS Encoder output

file = rserr.sig
samp. freq. = 1
time    =  0 secs
point# =  0 of 6200
value   =  1
Symbol Error introduced encoder data

file = rsout.sig
samp. freq. = 1
time    =  0 secs
point# =  0 of 3705
value   =  0
RS Decoder output with Corrected error bit
```

Figure 4-23. Sample Signal Waveform.

It was seen, from the above examples, that BOSS can be a viable tool in the design, analysis, simulation and testing of a Spread Spectrum transceiver. Systems can be put together with existing modules or new modules that need to be written. An IFF communication system can be simulated using BOSS. Environmental effects can also be simulated by basic signal amplitude, frequency, and phase modulation.

4.2.2 Multiple Access and Multipath Interference

An IFF system utilizes spread spectrum signalling to transmit information and as a result it can be treated as a typical spread spectrum system. We focused our attention on two of the environmental issues and we examined ways of evaluating their effect on the IFF system. The issues under consideration are:

Multiple access interference
Multipath interface

Multiple access interference is caused by multiple transmissions originating from different transmitters in the IFF system. Multipath interference is a result of a single transmission originating from a transmitter in the IFF system that arrives at the receiver site through multiple paths.

Several characteristics of the spread spectrum (IFF) system have to be identified before the model of the multiple access interference is complete. In the following we list the most important of these characteristics:

1. Transmitter-oriented or receiver-oriented spread spectrum systems,
2. Direct Sequence (DS) or Frequency Hopping (FH) signalling,
3. Type of signature (DS or FH) sequences used,
4. Type of modulation used,
5. Type of forward error correction coding used, and
6. Topology of the system.

Once the model of a multiple access spread spectrum system has been determined the performance of the system in the presence of multiple access interference becomes an issue of vital importance. Two measures of performance of a multiple access spread spectrum system have been widely adopted in the open literature; the bit error probability and the packet error probability. It is worth noting that evaluating bit or packet error probability of a spread spectrum multiple access system via exhaustive simulation techniques is formidable task, due to the fact that there is a large number of parameters that affect the system performance. For example, in a multiple access spread spectrum involving K transmitters there are 2K parameters that have an impact on the system performance. Even when K takes moderate values (e.g., K = 10) the number of parameters involved is unrealistically large. Consequently, most researchers have spent their efforts in analyzing multiple access spread spectrum systems, in order to derive analytical results that can be used to compute bit error packet error probabilities. In particular, a lot of work has been conducted in evaluating bit error and packet error probability for transmitter-oriented spread spectrum systems. Little or no work has been done to compute bit or packet error probabilities in receiver-oriented spread spectrum systems, one of the reasons being that they are difficult to analyze. It is worth noting that receiver-oriented spread spectrum systems are very practical and they are used quite extensively in the market. In transmitter-oriented spread spectrum systems every transmitter in the system has his own signature sequence (code). As a result a receiver must monitor all codes of the transmitters within range. This is reasonable if the receiver is a transponder since it has to monitor the code sequences of a limited number of interrogators, but it unrealistic for an interrogator receiver who has to monitor the spreading sequences of all transponders within the area of coverage. Not only the number of transponders within the area of coverage is large but their identity changes continuously as they move in and out of the interrogator's range. On the other hand in receiver-oriented spread spectrum systems a transmitter sends its information by using the signature sequence of the intended receiver. As a result, a receiver in a receiver-oriented spread spectrum system has to monitor only his own signature sequence, a considerable advantage compared with the requirement of a transmitter-oriented spread spectrum system, where a receiver has to monitor the signature sequences of all the transmitters in his range. We have already conducted considerable initial work to evaluate the packet error probability of receiver-oriented frequency hopped systems and the bit error probability of receiver-oriented direct sequence spread spectrum systems. Our next step is the evaluation of the probability in receiver-oriented direct sequence spread spectrum systems and an exhaustive comparison of transmitter-oriented and receiver-oriented multiple access spread spectrum system for our particular application (i.e., IFF system). In short, our research efforts have revealed that evaluation of the effect of multiple access interference on the IFF system is a feasible task provided that enough analytical work is conducted to avoid the formidable complexity of the exhaustive simulation techniques.

A similar approach, as the one mentioned above, has also been followed to assess the effect of multipath on the performance of the IFF system. Various multipath models exist in the open literature. These models are basically divided into two distinct classes:

The deterministic model.
The stochastic model.

The deterministic model corresponds to a deterministic description of the environment that causes the multipath effects, and it is very useful when multipath is caused by a small number of paths that can be accurately characterized. The stochastic model corresponds to a statistical model of the multipath and it is most appropriate when the multipath effects are caused by a large number of paths between transmitter and receiver that would be impossible to characterize in a deterministic way. It is worth noting that a good multipath model for a particular environment might be inappropriate for a different environment. As a result, quite often researchers resort to experimental data to derive an accurate multipath model. One of our intentions in this project is to rely on experimental measurements in order to derive an expression for the multipath model. The effect of multipath on the performance of the IFF system is going to be evaluated via simulations and analysis. If the multipath model used is deterministic, simulations will be the most appropriate tool to evaluate the system's performance. A sufficient number of software packages that can carry out the simulations have already been identified and purchased. If on the other hand, the multipath model is stochastic considerable analytical work is necessary before we resort to simulations. We have already identified in the open literature relatively simple stochastic multipath models that evaluate the performance of the system analytically. In some cases, where their analytical results are only approximations of the real system simulations are conducted to validate the analysis. Our approach, when stochastic models are utilized to describe the multipath effects will be to evaluate the probability of severe multipath effects, where by severe we imply that the information transmitted is distorted considerably (i.e., beyond recognition). In short, the evaluation of the effect of multipath on the IFF system is a difficult task that can be tackled via appropriate modeling (deterministic or stochastic), experimental measurements (to justify the models) and via simulation (using existing software packages) and analysis.

4.2.3 Spread Spectrum Modeling, and Transceiver Analysis and Simulation Using BOSS

The Spread Spectrum process is the spreading of information energy over a frequency band much larger than the required information bandwidth. This spreading operation makes the transmitted RF signal somewhat transparent in the channel. This feature is very desirable in hostile environments, and crowded channels. It reduces the probability of intercept by friendly or unfriendly unwanted receivers, as well as it increases the anti-jamming capability of the system. Spread spectrum also easily permits the use of Code Division Multiple Access which allows the use of multiple spread spectrum signaling over the same channel. The two major spread spectrum techniques are DS, and FH. Timing and range finding are also operations that can be performed by a DS Spread Spectrum System. DS systems are very well suited for low probability of intercept, while FH systems are better suited for anti-jamming scenarios.

4.2.3.1 <u>Direct Sequence Spread Spectrum System</u>. A transmitted DS spread spectrum signal used in conjunction with a BPSK modulator is modeled by:

$$x(t) = A d(t) g(t) \cos\{\omega_c t + \theta\}$$

where A is a constant, d(t) is the message signal, g(t) is the spreading waveform, ω_c is the carrier frequency, and θ is the carrier phase. d(t) and g(t) are modeled by:

$$d(t) = \sum_{k=-\infty}^{\infty} d_k p(t - kT_b)$$

$$g(t) = \sum_{j=-\infty}^{\infty} g_j p(t - jT_c)$$

d_k and g_j are the data bits and the spreading bits referred to as chips. T_b is the inverse data rate , and T_c is the inverse chip rate. p(t) is generally a rectangular pulse unless pulse shaping is used.

The received DS spread spectrum signal is modeled by:

$$y(t) = n(t) + \alpha x(t - \tau)$$

$$x(t - \tau) = A d(t - \tau) g(t - \tau) \cos(\omega_c t + \theta - \omega_c \tau)$$

n(t) is Additive White Gaussian Noise (AWGN), α is the channel attenuation, and τ is the channel delay. The above model does not include doppler shift which can easily be added, nor dispersion.

4.2.3.1.1 **Spreading Operation.** g(t) is the spreading waveform, it is usually the output of a maximal length sequence (MLS) generator. This MLS is a sequence of bits that repeats every 2^n -1 bits, thus forming a pseudo-random sequence. MLS sequences are easily implemented with n shift registers with preset initial conditions, exclusive-OR gates , and strategically chosen feedback paths. The feedback paths are governed by primitive polynomials of order n given by:

$$p(x) = c_n X^n + c_{n-1} X^{n-1} + c_{n-2} X^{n-2} + \ldots + c_2 X^2 + C_1 X + C_0$$

These primitive polynomials exhibit some nice correlation properties which makes receiver synchronization possible.

4.2.3.1.2 **Despreading Operation.** Despreading is possible if the primitive polynomial is known a priori at the receiver, the chip rate needs to be also known before synchronization can take place. A correlator receiver is used to line up the phases of the Pn generators of the transceiver. The despreading operation is generally split into two parts. The Code Acquisition or coarse acquisition, and Code Tracking or fine acquisition. Coarse acquisition techniques such as the Rapid Acquisition by Sequential Estimation (RASE), and the Sliding Correlator (SC), synchronize the receiver local PN generator to within one chip. Code Tracking loop such as the Tau Dither Loop, and the Delayed Locked Loop synchronize the transceiver PN generators inside one chip interval.

These synchronization techniques can measure the delay between the PN generator at the transmitter and the PN generator at the receiver.

4.2.3.2 Frequency Hopping Spread Spectrum.

4.2.3.2.1 Spreading Operation. In an FH spread spectrum transmitter, data information is first Frequency Shift Keying (FSK) modulated. A PN sequence generator is used to drive a frequency synthesizer. The output frequency of this synthesizer, which changes over a discrete number of preset frequencies controlled by the PN generator, is used to modulate, via simple mixing, the output of the FSK modulator. The synthesizer output frequency rate of change is called the hopping rate. The output of the FSK modulator is given by:

$$x(t) = A \cos\left\{2\pi\left(f_c + d(t)\frac{\Delta}{2}\right)t + \theta(t)\right\}$$

f_c is the carrier frequency, d(t) = + or - 1 , Δ is the spacing between the two FSK tones, and θ is the phase introduced by the FSK modulator.

The FH transmitted signal can then be modeled as:

$$x_t(t) = A \cos\left\{2\pi\left(f_c + d(t)\frac{\Delta}{2} + f_i\right)t + \phi\right\}$$

$f_c + f_i$ is the ith frequency in the discrete hopping band, ϕ is the transmitted carrier phase.

4.2.3.2.2 Despreading Operation. As with DS systems, the primitive polynomial, as well as the chip rate has to be known or generated at the receiver of a FH spread spectrum transceiver. The acquisition process consists also of a two part system. First Code Acquisition or coarse acquisition is performed, CAMP and WAIT is a popular technique. This technique is very similar to the classical Frequency Demodulator Using Feedback.

Once coarse acquisition is achieved, Tracking Loops for fine acquisition are used. The EARLY-LATE GATE TRACKING SYSTEM is a very popular fine tracking system. The heart of both the camp and wait, and the early-late gate tracking loops is the VCO that drives the receiver local PN generator. The synchronization can be sustained even in the presence of large disturbances, such as jammers, as long as the phase delay between the PN generators of the transceiver is less than $T_H = 1/f_H$, where f_H is the hopping frequency.

4.3 SIGNAL GENERATION RESEARCH

This is a summary report of the signal generation group working on the TESTS project for the Spring term 1991. The investigators include Dr. D. Malocha, Dr. T. Kasparis, and Mr. A. J. Vigil. The purpose of the group was to explore hardware and software options for signal generation, signal conditioning, and signal detection applicable to typical spread spectrum communication systems.

This introduction will provide a brief overview of the work conducted over this past term and provide introductions to the various sections to follow. Various aspects of the signal generation stimulation and detection, from a hardware perspective, were investigated. The results are included in Sections 4.3.1 and 4.3.2.

Section 4.3.1 provides the mathematical fundamentals for in-phase and quadrature signal modeling. This was conducted primarily as a tutorial to provide the background for all the investigators as to approaches in modeling and conditioning of signals. The in-phase quadrature modeling approach is both simple and elegant and provides great insight for methods of modeling signals.

Section 4.3.2 is a discussion of time-dependent formats for communications systems. There are a variety of different types of modulation formats, which include direct sequence, frequency hopping, pulse width, pulse position, and cascading of time-dependent modulation. These are very briefly presented in block diagram form as examples for the reader.

The results of the effort in the Spring term were to examine and understand potential problems and solutions for RF signal generation, detection, and conditioning. The investigators explored various aspects of spread spectrum communications and their potential implementations. One of the conclusions reached is that it is very difficult to meet the demanding sampling requirements of an arbitrary spread spectrum signal due to its high bandwidth and data rates. Based on the study this semester, a hardware approach seems most feasible and poses the least risk. The particulars, in terms of design of the various pieces of hardware, were not conducted during this phase of the project. However, the investigators did look at some typical numbers, and it does appear that components and subsystems are available to accomplish the tasks necessary to meet the TEMP objectives.

4.3.1 In-Phase and Quadrature Signal Modeling Fundamentals

The communication system test tool under development requires the modeling and synthesis of RF signals. A set of RF signal model conventions are presented. A set of signal model conventions such as this will provide the basis for modeling RF signals under the influence of attenuation, time delay, dispersion and superposition. A model such as this will provide the foundation for computer simulations of RF signals.

4.3.1.1 Signal Model. The given model is based on a center frequency for simulation and represents an RF signal in terms of its time dependent in phase and quadrature (I and Q) components, or its cosine and sine envelopes. This is shown to be equivalent to modeling an RF signal on the basis of its instantaneous amplitude and phase. Time sampling and quantization may be applied to this model in order to make it suitable for computer simulation. A consistent frequency domain model is shown to be compatible with conventional fast Fourier transform techniques. It is shown how the modeling conventions introduced may be used to apply attenuation, time delay, frequency shift, dispersion and superposition to RF signals modeled by their I/Q components.

4.3.1.1.1 **Cosine and Sine Envelopes.**

Purpose: Complete characterization of an RF signal by two video signals - I/Q Model.

An RF signal g(t) of known bandwidth about a given center frequency f_c may be modeled completely in terms of two sinusoids, $\cos(2\pi f_c t)$ and $\sin(2\pi f_c t)$ with time varying amplitudes $E_I(t)$ and $E_Q(t)$ using

$$g(t) = E_I(t)\cos(2\pi f_c t) + E_Q(t)\sin(2\pi f_c t)$$

Knowledge of the cosine envelope $E_I(t)$ and the sine envelope $E_Q(t)$ allows for reconstruction of the RF signal g(t) as shown in Figure 4-24.

The example used in Figure 1 corresponds to a Mark XII Mode 1 interrogation at an RF frequency of 10 MHz. The example assumes a carrier shift of 30 degrees between P_1 and P_3 and an ISLS pulse with an independent phase reference. The carrier frequency of 10 MHz was chosen for this example because higher carrier frequencies are more difficult to illustrate.

4.3.1.1.2 **Amplitude and Phase Representation.**

Purpose: Complete characterization of an RF signal by two video signals - amplitude/phase model.

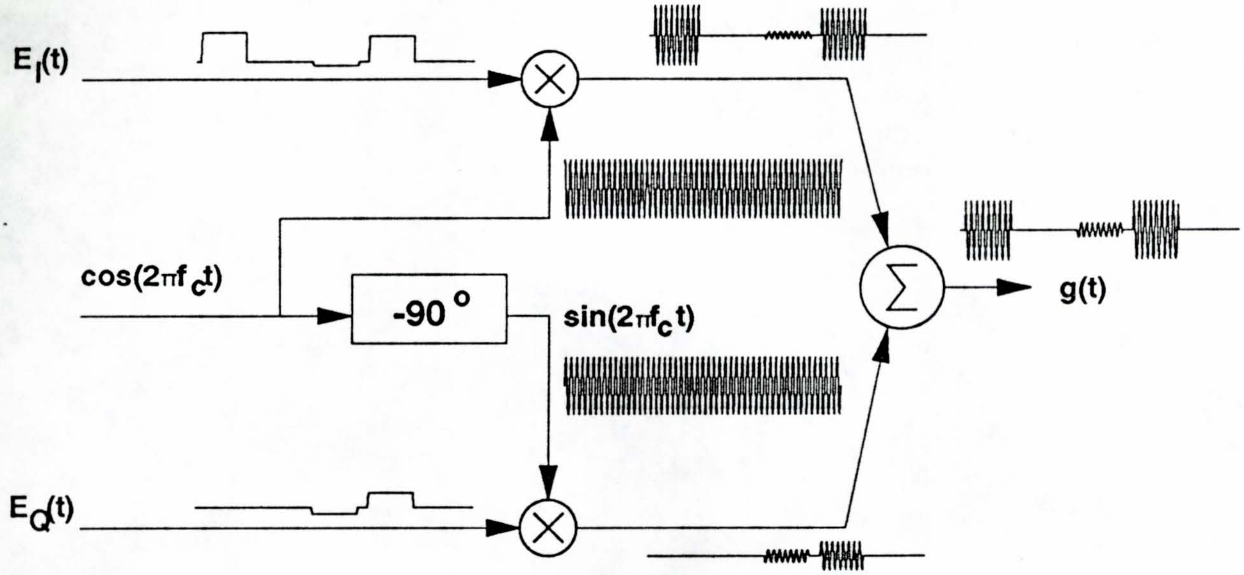


Figure 4-24. Reconstruction of an RF Signal From Its I/Q Model.

An equivalent RF signal modeling format involves representing the RF signal g(t) by a single sinusoid of frequency f_c with a time dependent amplitude A(t) and a time dependent relative phase $\Phi(t)$ using

$$g(t) = A(t)\cos(2\pi f_c t - \Phi(t))$$

The polar RF amplitude representation, A(t), and phase representation, $\Phi(t)$ are related to the rectangular RF signal envelopes $E_I(t)$ and $E_Q(t)$ through the rectangular to polar conversion equations

$$A(t) = \sqrt{E_I^2(t) + E_Q^2(t)}$$

and

$$\Phi(t) = \tan^{-1}\left(\frac{E_I(t)}{E_Q(t)}\right)$$

where the inverse tangent function represents all four quadrants. Knowledge of the envelope A(t) and the phase * allows for reconstruction of the RF signal g(t) as shown in Figure 4-25. The example illustrated in Figure 4-25 employs the same RF signal illustrated in Figure 4-24.

4.3.1.1.3 **Time Sampling.**

Purpose: To maintain RF signal model accuracy while applying time sampling to its I/Q model components.

Time sampling refers to the mapping of a signal from a continuous time domain to a discrete time domain. Time sampling may be applied to the I/Q model components $E_I(t)$ and $E_Q(t)$ using

$$E_{Is}(t) = \sum_{n=-\infty}^{\infty} E_I(nT_s)\delta(t - nT_s)$$

and

$$E_{Qs}(t) = \sum_{n=-\infty}^{\infty} E_Q(nT_s)\delta(t - nT_s)$$

where $\delta(t)$ is the Dirac delta distribution and T_s is the sampling period. $E_{Is}(t)$ and $E_{Qs}(t)$ are therefore time sampled representations of $E_I(t)$ and $E_Q(t)$. The sampling frequency f_s is the inverse of the sampling period T_s, or

$$f_s = \frac{1}{T_s}$$

The Nyquist sampling theorem gives the criterion which determines the accuracy of a sampling operation. The Nyquist theorem states that the sampling frequency must be at least twice the total signal bandwidth of a signal in order for the signal to be reconstructed from its sampled form.

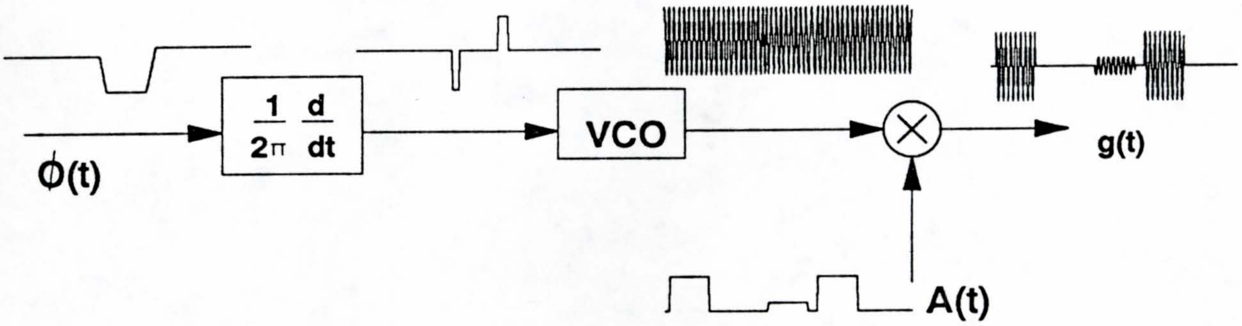


Figure 4-25. Reconstruction of an RF Signal From Its Amplitude/Phase Model.

The "total signal bandwidth" is the total space occupied by the signal in the frequency domain. This "total signal bandwidth" should not be confused with the 3 dB bandwidth. The total signal bandwidth is sometimes approximated as the bandwidth where spectral features (sidelobes) have been attenuated to an arbitrarily insignificant fraction of the main spectral components (main lobe). This fraction is nominally between 50 and 100 dB.

In the case of the I/Q model, sampling both $E_I(t)$ and $E_Q(t)$ at a rate equal to or greater than the total bandwidth of the RF signal g(t) satisfies the Nyquist criterion because sampling two orthogonal signal components effectively doubles the sampling rate on the composite signal.

It is a common practice to sample higher than the Nyquist rate. It is common for systems to employ sampling at double the Nyquist rate or higher. In the case of sampling I/Q components, sampling at twice the Nyquist rate means sampling both $E_I(t)$ and $E_Q(t)$ at a frequency equal to twice the RF signal bandwidth.

The strength of the I/Q model is the fact that the sampling rate is determined by the RF signal bandwidth and not by the center frequency of the carrier. This provides for accurate signal modeling at sampling rates lower than those needed to otherwise reproduce the RF signal.

As an example, suppose an RF signal to be modeled has a center frequency of 10 GHz and a 90 dB bandwidth of 100 MHz. Suppose also that the I/Q format was used to model this signal. If the simulation sampling took place at twice the Nyquist rate the sampling frequency would be 200 MHz and the sampling interval would be 5 nanoseconds.

4.3.1.1.4 **Quantization.**

Purpose: To maintain RF signal amplitude dynamic range while digitizing its time sampled I/Q model components.

Signal modeling is subject to errors when a sequence of signal samples are digitized. The resolution of the digitizing process determines the amplitude dynamic range of the signal model.

Each bit of signal quantization accuracy corresponds to about 6 dB of amplitude dynamic range. Each decimal point of signal quantization accuracy represents 20 dB of amplitude dynamic range.

As an example, suppose that 70 dB of dynamic range were required in a digital simulation. This would require a quantization accuracy of 12 bits (6 dB per bit times 12 bits yields 72 dB resolution) or 4 decimal places (20 dB per decimal place times 4 places yields 80 dB resolution).

4.3.1.1.5 **Frequency Domain Model.**

Purpose: To establish conventions for the application of a frequency domain model to the quantized time sampled I/Q component model.

A digitized time sampled I/Q model of a finite time signal lends itself directly to frequency domain study through computer Fast Fourier Transform (FFT) methods.

Application of the FFT to a digitized time sampled I/Q model is best illustrated through an example. The example is again a Mark XII Mode 1 interrogation, whose I/Q model is illustrated in Figure 4-26. The center frequency for this example is 1000 MHz. The sampling period T_s is 0.01 microseconds. 1000 samples are considered for a total time duration of 10 microseconds. The time corresponding to the first sample is 0 (zero) microseconds and the time corresponding to the 1000'th sample is 9.99 microseconds. The 1000 term sequence to be transformed is the set of complex numbers $E_I(nT_s)+jE_Q(nT_s)$ where j is the imaginary operator and n corresponds to a member of the set of 1000 integers from 0 to 999.

The result of the FFT is illustrated in Figure 4-27. The result is the frequency domain model which is also a 1000 term sequence of complex numbers. The bandwidth BW of the frequency domain model is equal to the inverse of the time sampling period T_s, or

$$BW=\frac{1}{T_s}$$

The first point of the frequency domain data corresponds to the center frequency of the simulation, which was 1000 MHz. Points which follow are separated from each other by the spacing Δf which is calculated using

$$\Delta f_s=\frac{1}{NT_s}$$

where N is the number of points in the simulation. Since N equals 1000 and T_s is 0.01 microseconds, the frequency spacing Δf equals 0.1 megahertz.

The frequencies corresponding to each point continue to rise from the simulation center frequency to the simulation high frequency, which is half way through the frequency domain data. This point corresponds to the frequency $f_c+\frac{1}{2}BW$. That data point also represents the lowest frequency modeled, which is $f_c-\frac{1}{2}BW$. The frequencies resume their rise until the last point, which corresponds to the frequency $f_c-\Delta f$. In the example, the frequency domain data begins at 1000 MHz and continues to 1050 MHz. It then jumps down to 950.1 MHz and resumes rising to 999.9 MHz.

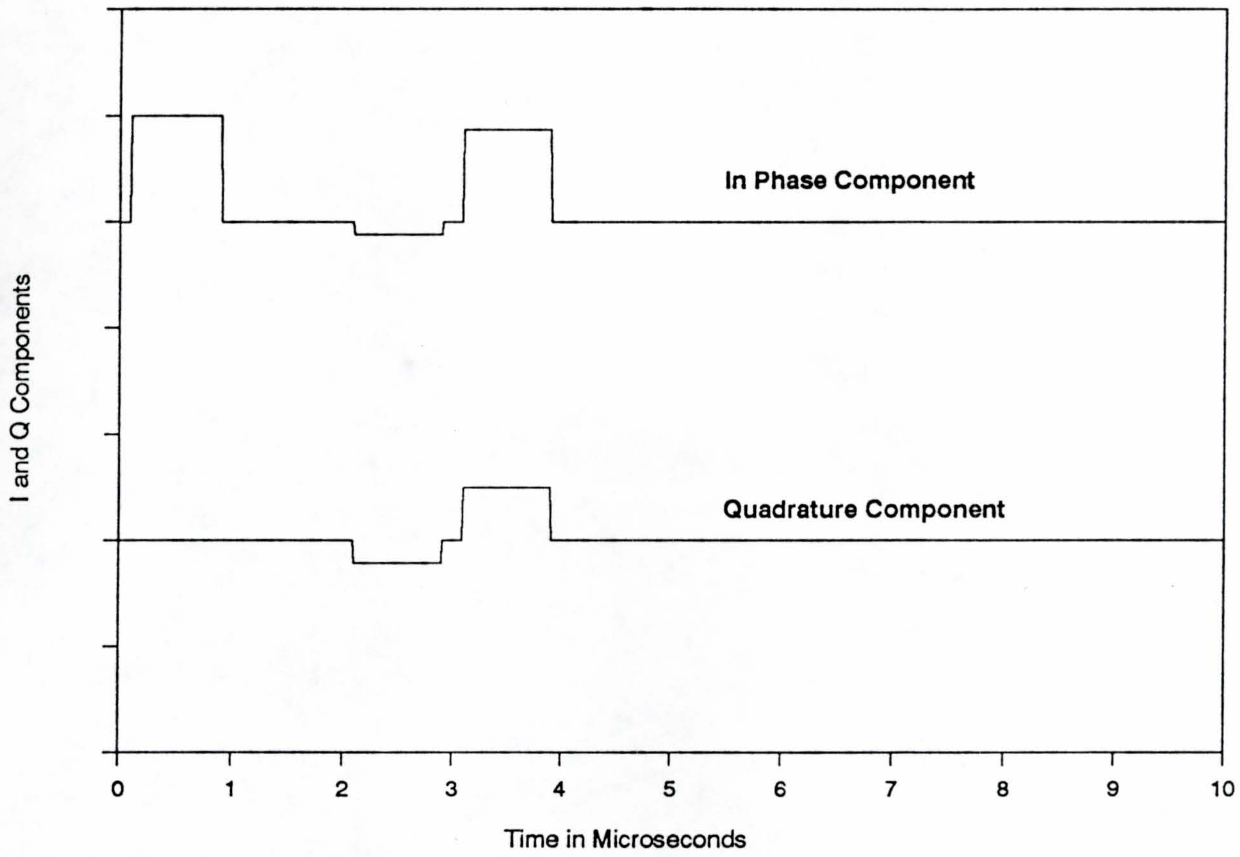


Figure 4-26. Time Domain I/Q Model of a Mark XII Mode 1 Interrogation.

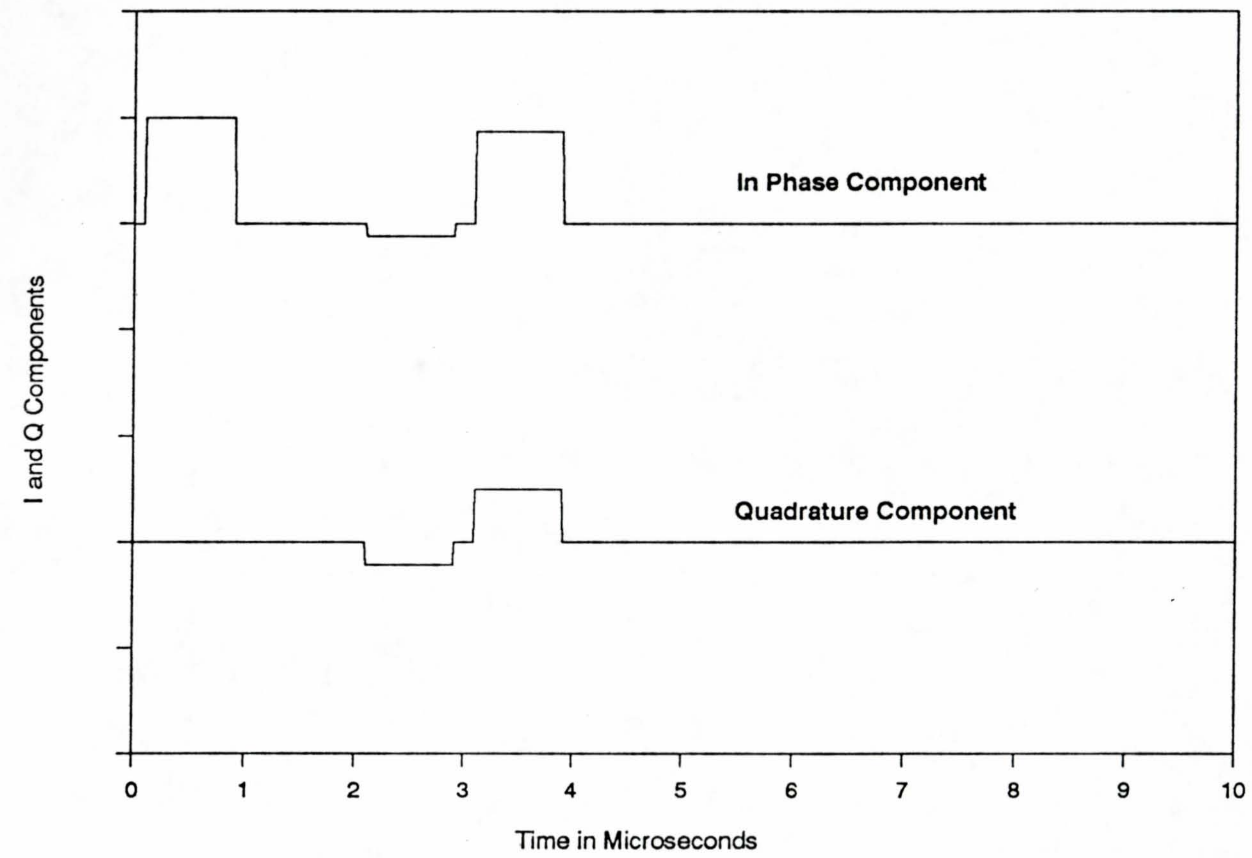


Figure 4-26. Time Domain I/Q Model of a Mark XII Mode 1 Interrogation.

4.3.1.1.6 **Attenuation or Gain.**

Purpose: To model the effects of antenna gain, propagation loss, polarization loss or reflection loss on the amplitudes of RF signals modeled through the I/Q component approach.

Consider a linear attenuation k_{at} applied to a signal $g(t)$ with I/Q envelopes $E_I(t)$ and $E_Q(t)$. The resulting signal would be modeled

$$k_{at}g(t) = k_{at}E_I(t)\cos(2\pi f_c t) + k_{at}E_Q(t)\sin(2\pi f_c t)$$

The new I and Q envelopes would be $k_{at}E_I(t)$ and $k_{at}E_Q(t)$.

Figure 4-28 illustrates the I/Q model for the signal which results when an attenuation of 0.5 is applied to the signal illustrated in Figure 4-26.

4.3.1.1.7 **Carrier Phase Shift.**

Purpose: To model the effects of a carrier phase shifts on RF signals modeled through the I/Q component approach.

Consider an RF signal $g(t)$ subject to a carrier phase shift of Θ. The resulting RF signal $g_\Theta(t)$ would be modeled

$$\begin{aligned}
g_\Theta(t) &= E_I(t)\cos(2\pi f_c t + \Theta) + E_Q(t)\sin(2\pi f_c t + \Theta)\\
&= E_I(t)[\cos(2\pi f_c t)\cos\Theta - \sin(2\pi f_c t)\sin\Theta]\\
&\quad + E_Q(t)[\sin(2\pi f_c t)\cos\Theta + \cos(2\pi f_c t)\sin\Theta]\\
&= [E_I(t)\cos\Theta + E_Q(t)\sin\Theta]\cos(2\pi f_c t)\\
&\quad + [E_Q(t)\cos\Theta - E_I(t)\sin\Theta]\sin(2\pi f_c t)
\end{aligned}$$

The new I and Q envelopes would be $E_I(t)\cos\Theta + E_Q(t)\sin\Theta$ and $E_Q(t)\cos\Theta - E_I(t)\sin\Theta$. (See Figure 4-29)

4.3.1.1.8 **Time Delay.**

Purpose: To model the effects of propagation or response time delay on RF signals modeled through the I/Q component approach.

Consider a time delay of ΔT applied to an RF signal $g(t)$. The resulting signal would be modeled through the I/Q approach using

$$\begin{aligned}
g(t-\Delta T) &= E_I(t-\Delta T)\cos(2\pi f_c(t-\Delta T)) + E_Q(t-\Delta T)\sin(2\pi f_c(t-\Delta T))\\
&= E_I(t-\Delta T)\cos(2\pi f_c t - 2\pi f_c\Delta T) + E_Q(t-\Delta T)\sin(2\pi f_c t - 2\pi f_C\Delta T)\\
&= [E_I(t-\Delta T)\cos(2\pi f_c\Delta T) - E_Q(t-\Delta T)\sin(2\pi f_c\Delta T)]\cos(2\pi f_c t)\\
&\quad + [E_I(t-\Delta T)\sin(2\pi f_c\Delta T) + E_Q(t-\Delta T)\cos(2\pi f_c\Delta T)]\sin(2\pi f_c t)
\end{aligned}$$

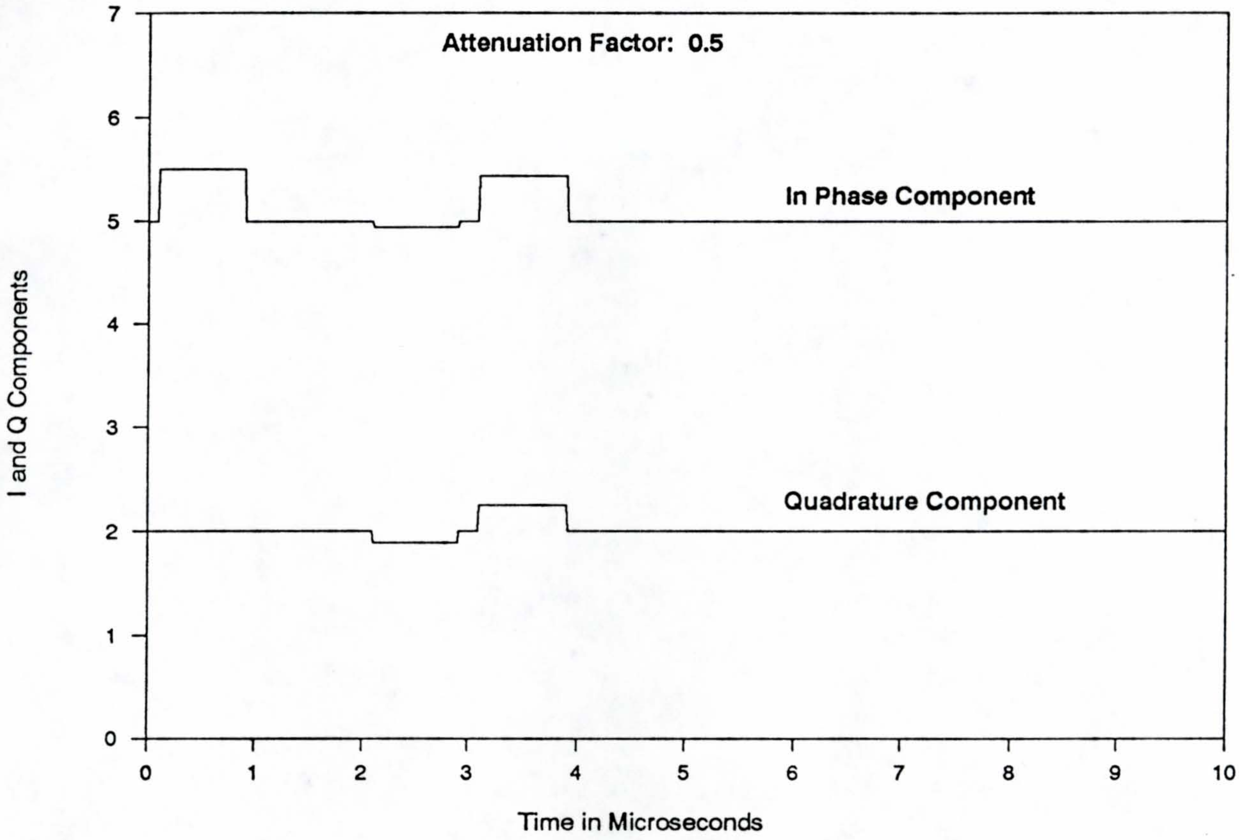


Figure 4-28. I/Q Model of the Mark XII Mode 1 Interrogation Example After Undergoing an Attenutation of 0.5.

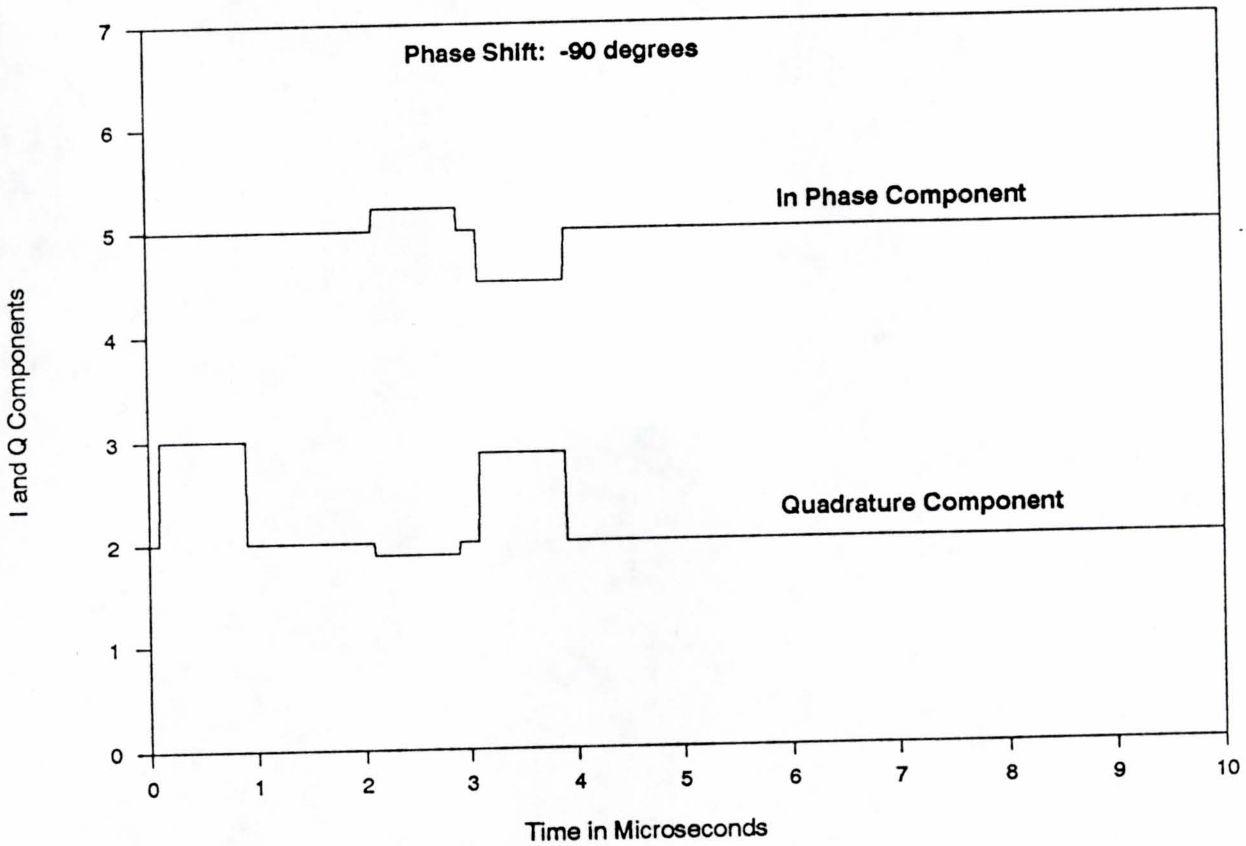


Figure 4-29. I/Q Models of the Mark XII Mode 1 Interrogation Example After Undergoing a Phase Shift of -90°.

This is equivalent to a time shift in the I and Q envelopes and a phase shift in the carrier. The resulting I and Q envelopes would be $E_I(t-\Delta T)\cos(2\pi f_c\Delta T)-E_Q(t-\Delta T)\sin(2\pi f_c\Delta T)$ and $E_I(t-\Delta T)\sin(2\pi f_c\Delta T)+E_Q(t-\Delta T)\cos(2\pi f_c\Delta T)$.

Figure 4-30 illustrates the I/Q model of the signal illustrated in Figure 4-26 after being subject to 3.0005 microseconds of time delay.

4.3.1.1.9 **Frequency Shift.**

Purpose: To model the effects of frequency shift from sources such as signal agility and Doppler on RF signals modeled through the I/Q component approach.

Consider a frequency shift of Δf applied to an RF signal $g(t)$. The resulting RF signal $g_{\Delta f}(t)$ is modeled using

$$\begin{aligned}
g_{\Delta f}(t) &= E_I(t)\cos(2\pi(f_c+\Delta f)t)+E_Q(t)\sin(2\pi(f_c+\Delta f)t)\\
&= E_I(t)[\cos(2\pi f_c t)\cos(2\pi\Delta f t)-\sin(2\pi f_c t)\sin(2\pi\Delta f t)]\\
&\quad +E_Q(t)[\sin(2\pi f_c t)\cos(2\pi\Delta f t)+\cos(2\pi f_c t)\sin(2\pi\Delta f t)]\\
&= [E_I(t)\cos(2\pi\Delta f t)+E_Q(t)\sin(2\pi\Delta f t)]\cos(2\pi f_c t)\\
&\quad +[E_Q(t)\cos(2\pi\Delta f t)-E_I(t)\sin(2\pi\Delta f t)]\sin(2\pi f_c t)
\end{aligned}$$

The resulting I and Q envelopes would be $E_I(t)\cos(2\pi\Delta f t)+E_Q(t)\sin(2\pi\Delta f t)$ and $E_Q(t)\cos(2\pi\Delta f t)-E_I(t)\sin(2\pi\Delta f t)$.

Figure 4-31 illustrates the I/Q model of the signal illustrated in Figure 4-26 after being subject to 0.4 megahertz of positive frequency shift.

4.3.1.1.10 **Dispersion.**

Purpose: To model effects such as diffuse path propagation dispersion and other filter type effects on RF signals modeled through the I/Q component approach.

The effects of a linear transfer function $H(f)$ on a signal $g_1(t)$ may be modeled in the frequency domain using

$$G_2(f)=H(f)G_1(f)$$

where the resulting signal is $g_2(t)$ with Fourier transform $G_2(f)$ and $G_1(f)$ is the Fourier transform of $g_1(t)$. $g_2(t)$ may be modeled directly in the time domain using convolution. If $h(t)$ is the Fourier transform of $H(f)$, then

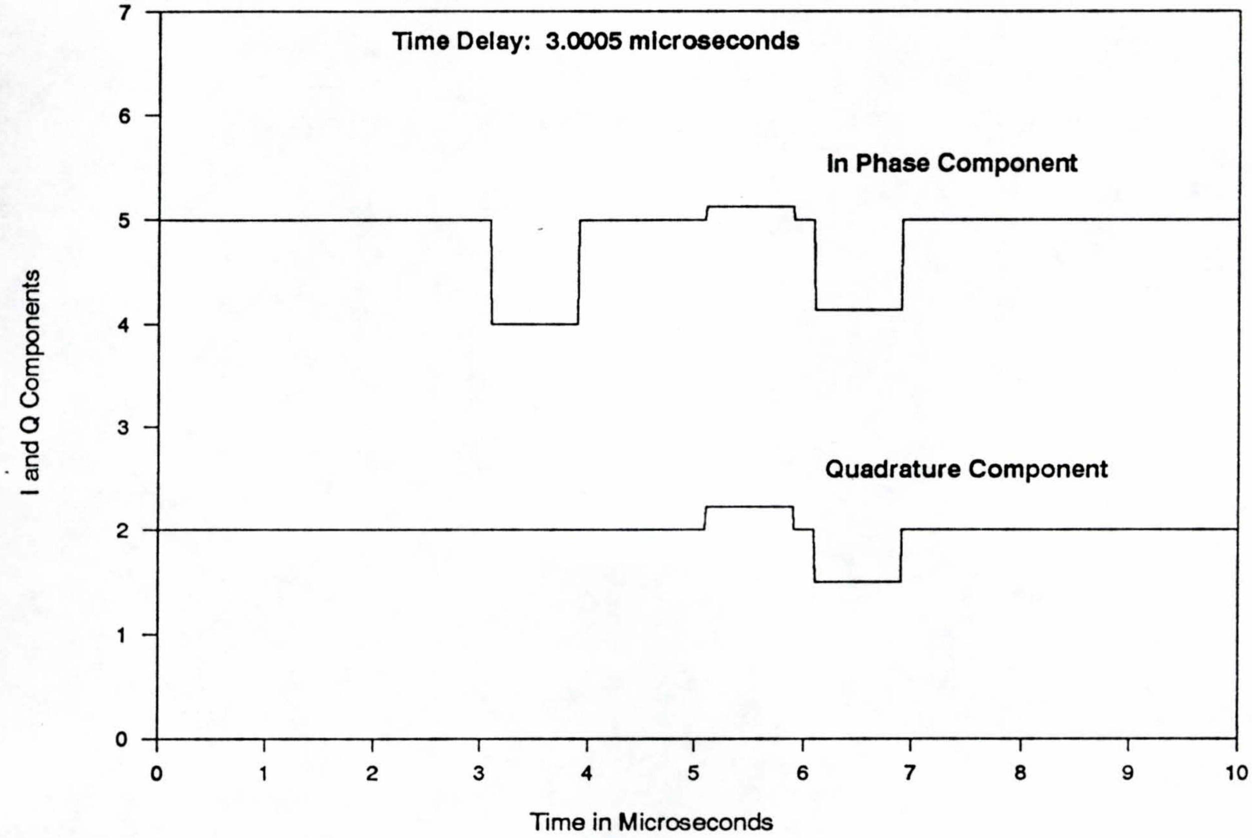


Figure 4-30. I/Q Model of the Mark XII Mode 1 Interrogation Example after Undergoing a Time Delay of 3.005 Microseconds.

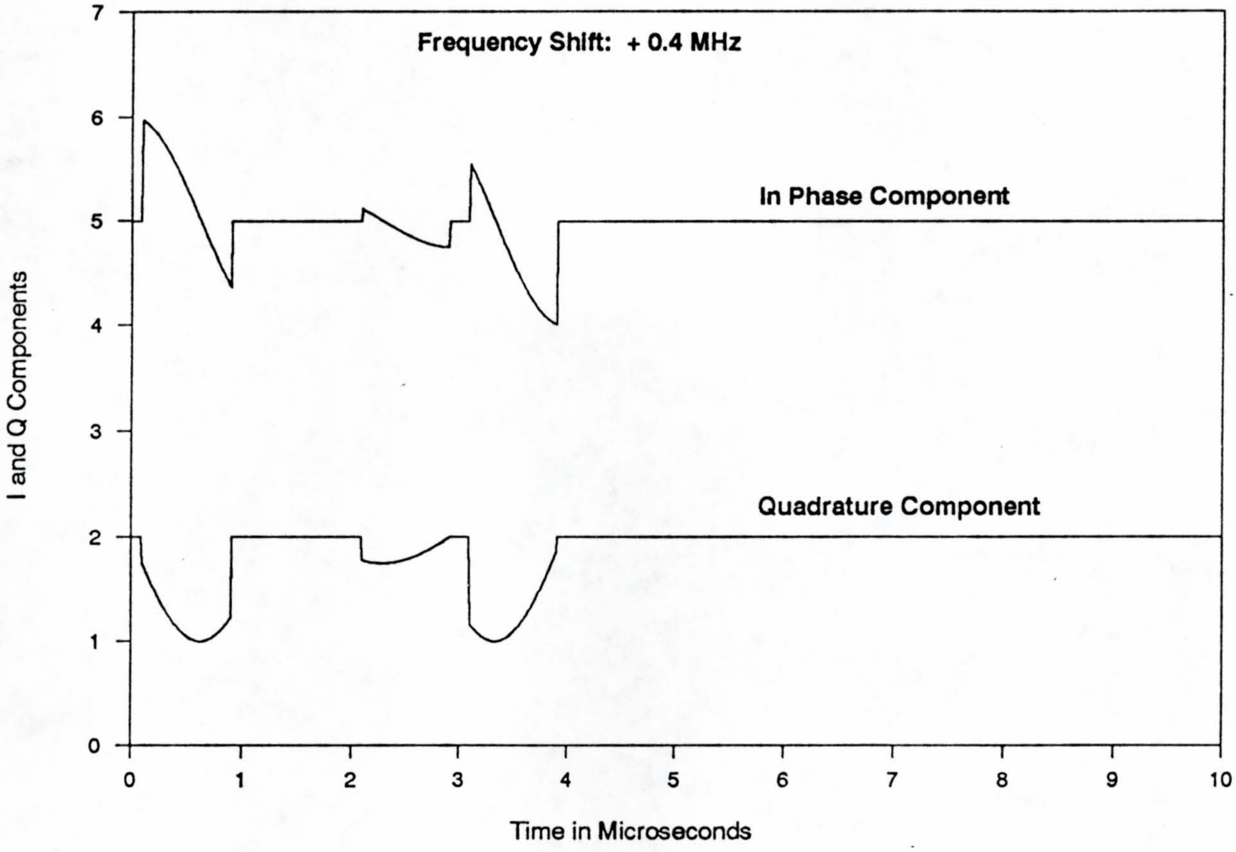


Figure 4-31. I/Q Model of the Mark XII Mode 1 Interrogation Example after Undergoing a Positive Frequency Shift of 0.4 Megahertz.

$$g_2(t) = h(t) \otimes g_1(t) = \int_{-\infty}^{\infty} h(\tau) g_1(t-\tau) d\mathrm{T}$$

Convolution may be applied to I/Q signal models. Suppose $g_1(t)$ is sampled with a sampling period T_s. In the case where $h(t)$ is causal and limited in time to $0 \le t \le NT_s$, $g_2(nT_s)$ is modeled using

$$E_{2I}(nT_s) = \frac{1}{2} T_s \sum_{k=0}^{N} h_I(kT_s) E_{1I}((n-k)T_s) - h_Q(kT_s) E_{1Q}((n-k)T_s)$$

and

$$E_{2Q}(nT_s) = \frac{1}{2} T_s \sum_{k=0}^{N} h_I(kT_s) E_{1Q}((n-k)T_s) + h_Q(kT_s) E_{1I}((n-k)T_s)$$

where $h_I(t)$ and $h_Q(t)$ are the I/Q model components of $h(t)$, $E_{1I}(t)$ and $E_{1Q}(t)$ are the I/Q model components of $g_1(t)$ and $E_{2I}(t)$ and $I_{2Q}(t)$ are the I/Q model components of $g_2(t)$. In this example $g_2(t)$ is also sampled with a sampling period T_s.

As an example, consider the band pass filter response

$$h(t) = e^{-\frac{t}{\tau}} \cos(2\pi f_b t)$$

This represents a first order band pass filter with a center frequency f_b and a 3 dB bandwidth of $\frac{1}{\pi\tau}$. This filter response may be convolved with the signal modeled in Figure 4-26. Figure 4-32 illustrates the example where the band pass filter center frequency f_b equals 1001 MHz and time constant τ equals 0.075 microseconds for a 3 dB bandwidth of 4 megahertz. Figure 4-32 illustrates the I/Q models of the input signal, the filter response and the output signal.

4.3.1.1.11 **Superposition of Signals.**

Purpose: To model how two signals modeled through the I/Q component approach may be added together within the framework of that approach.

Suppose three signals $g_1(t)$, $g_2(t)$ and $g_3(t)$ are time sampled with a sampling period T_s. Suppose also that $g_3(t)$ is the superposition, or sum, of $g_1(t)$ and $g_2(t)$. Applying the I/Q model to all three signals, $g_3(t)$ is modeled using

$$E_{3I}(nT_s) = E_{1I}(nT_s) + E_{2I}(nT_s)$$

and

$$E_{3Q}(nT_s) = E_{1Q}(nT_s) + E_{2Q}(nT_s)$$

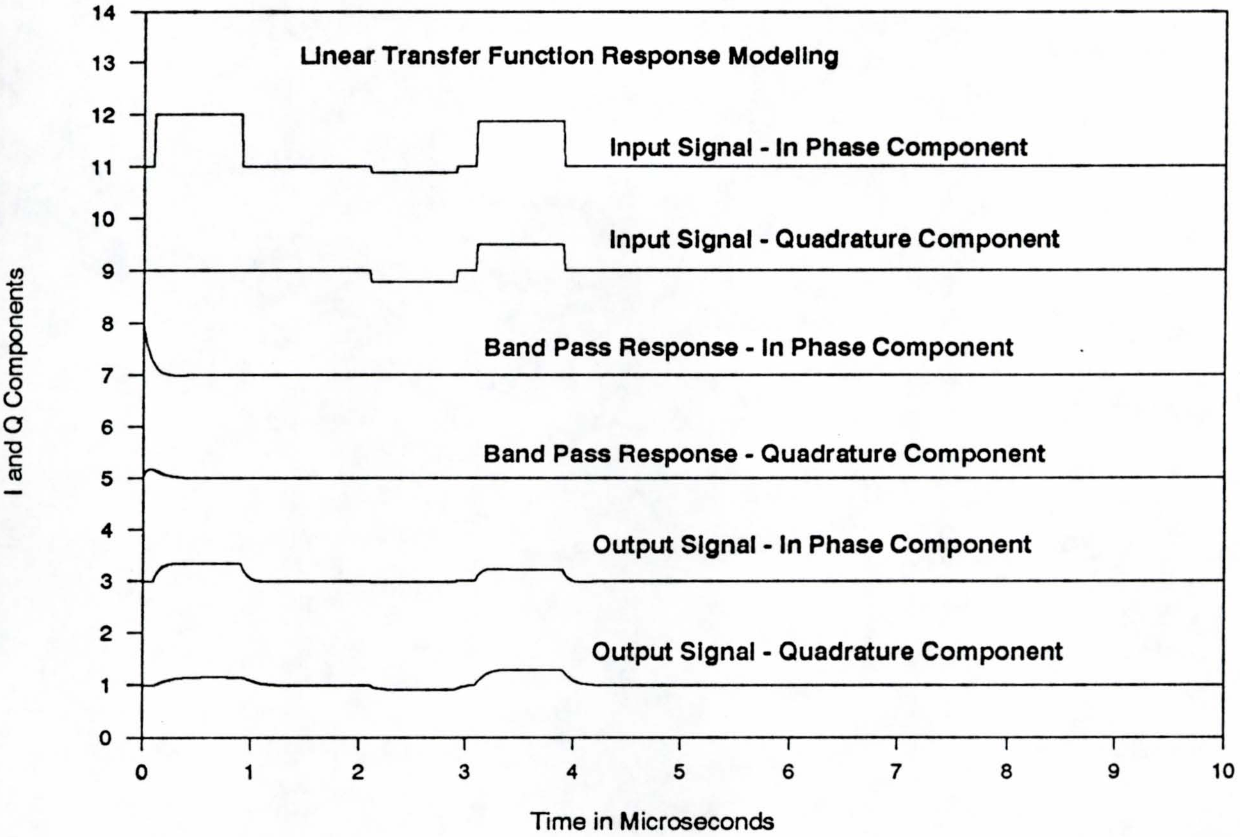


Figure 4-32. I/Q Model of the Mark XII Mode 1 Interrogation Example after Undergoing Time Dispersion Through a Band Pass Filter.

As an example, let $g_1(t)$ be the input signal illustrated in Figure 4-32 and let $g_2(t)$ be the output signal illustrated in Figure 4-32 subject to a time delay of 0.25 microseconds and an attenuation of 0.3. The superposition of these two signals is illustrated in Figure 4-33.

4.3.2 Time Dependent Formats for Communication Systems

One reason for applying spread spectrum to communication systems is to establish secure communications. Time dependent formatting may be applied to spread spectrum communications and to other modulation techniques to enhance their levels of security.

The concept of time dependent modulation formats is presented. The examples which then follow illustrate how time dependent formatting may be applied to direct sequence spread spectrum modulation, frequency hopping spread spectrum modulation, pulse width modulation and pulse position modulation. The simulation system complexity added by introducing time dependent modulation formats is discussed.

4.3.2.1 Operation of Communication System With Time Dependent Modulation Formats. A point to point communication system consists of a transmitter and a receiver. Time dependent modulation formats may be thought of as modulation systems whose parameters vary with time. This means that the operation of both the transmitter and the receiver changes with time. This concept is best explained through the use of illustrations.

A block diagram of a generalized time dependent modulation transmitter is shown in Figure 4-34. The modulator generates signals in time as a function of both the time varying message data and the time dependent modulation control signal. The time dependent control signal is generated through the interpretation of time dependent code sequences which are in turn generated from a time dependent code generator. Communications security depends on the fact that the time dependent code generator uses code generation algorithms and time and initialization conventions which are unknown to those who are foreign to the specific communication process.

For clarity it should be stated that the "Modulator" block in Figure 4-34 includes any error correction encoding or preliminary processing done on the message data. It is also shown that modulation takes place at a convenient "I.F." or "Intermediate Frequency" which is convenient to the system designer. An "L.O." or "Local Oscillator" is used to raise the signal to the desired transmission frequency. These details are common to most communication systems.

A time dependent modulation receiver is pictured in Figure 4-35. Again, a time reference, an initial condition reference and a code generation algorithm are required. This time they are used in demodulation or interpreting the received signal. Successful demodulation requires that the time reference, initialization

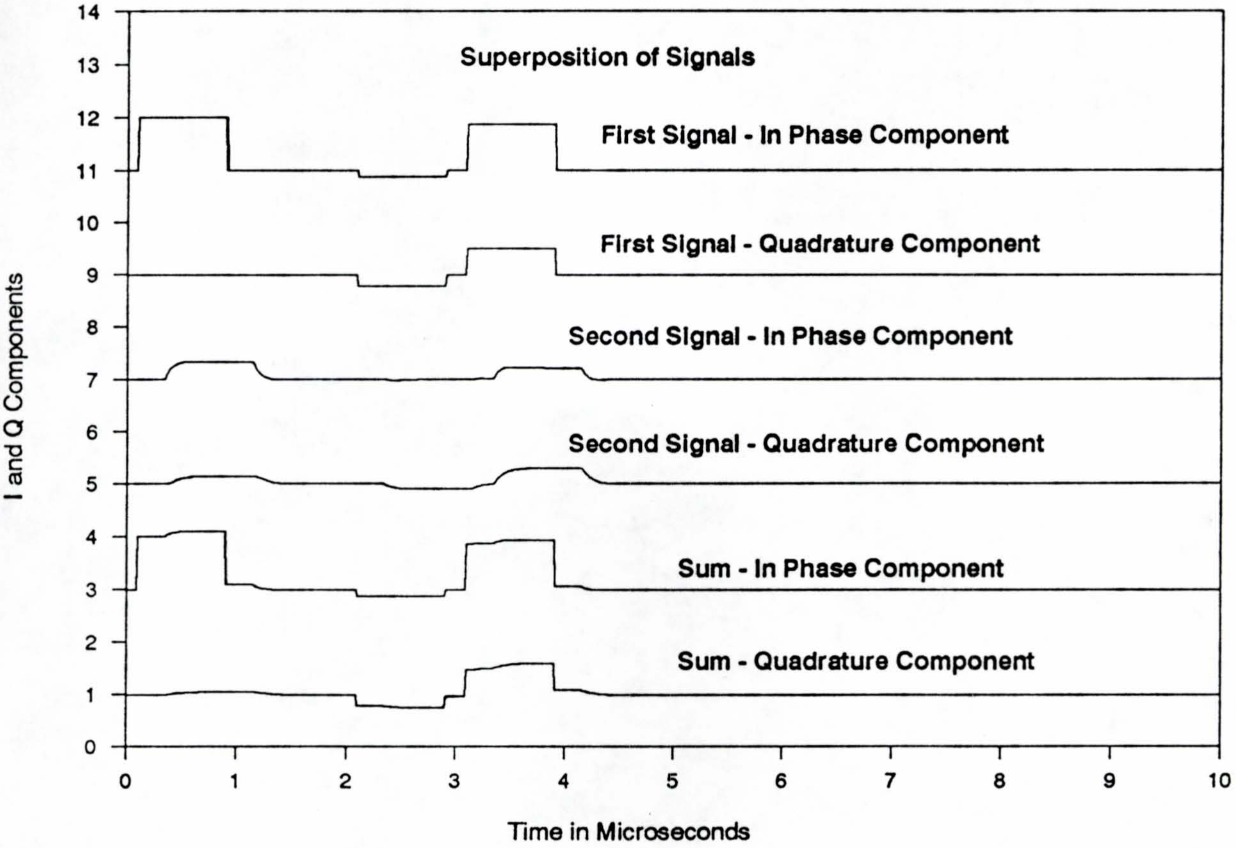


Figure 4-33. I/Q Model of the Mark XII Mode 1 Interrogation Example Undergoing Superposition.

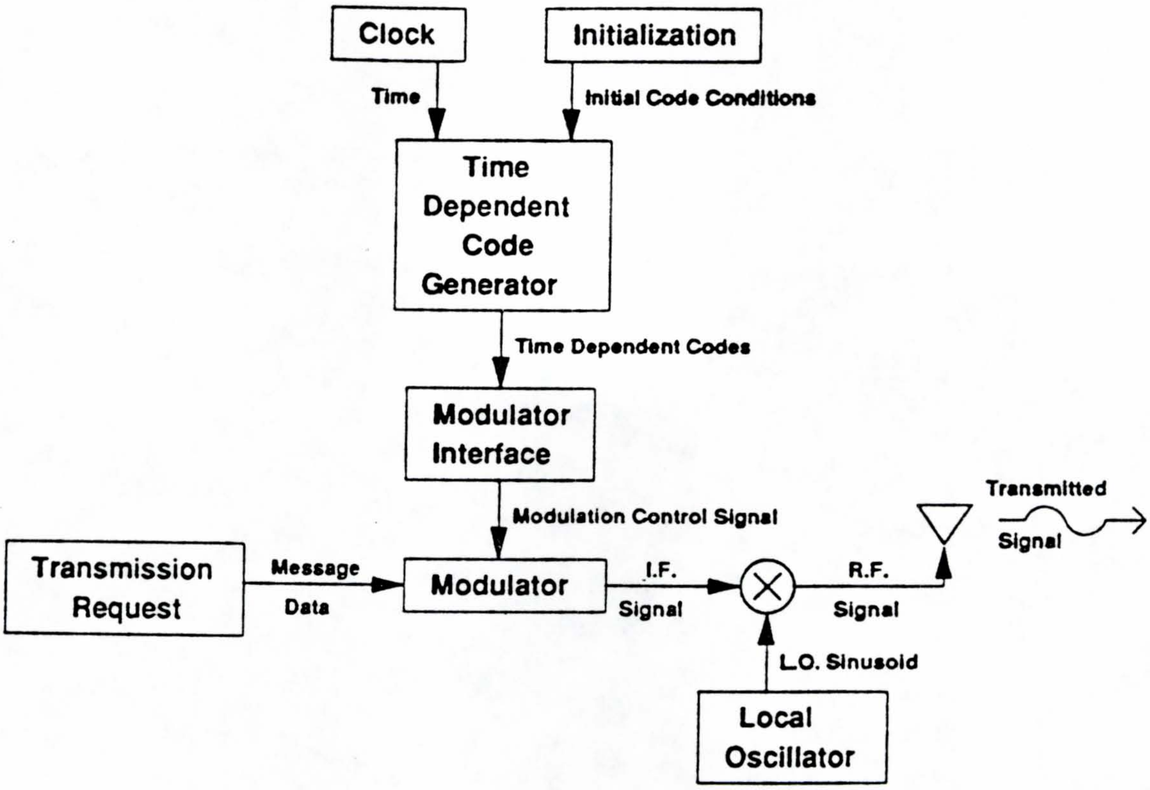


Figure 4-34. Block Diagram of Transmitter for a Communication System Employing Time Dependent Modulation Formats.

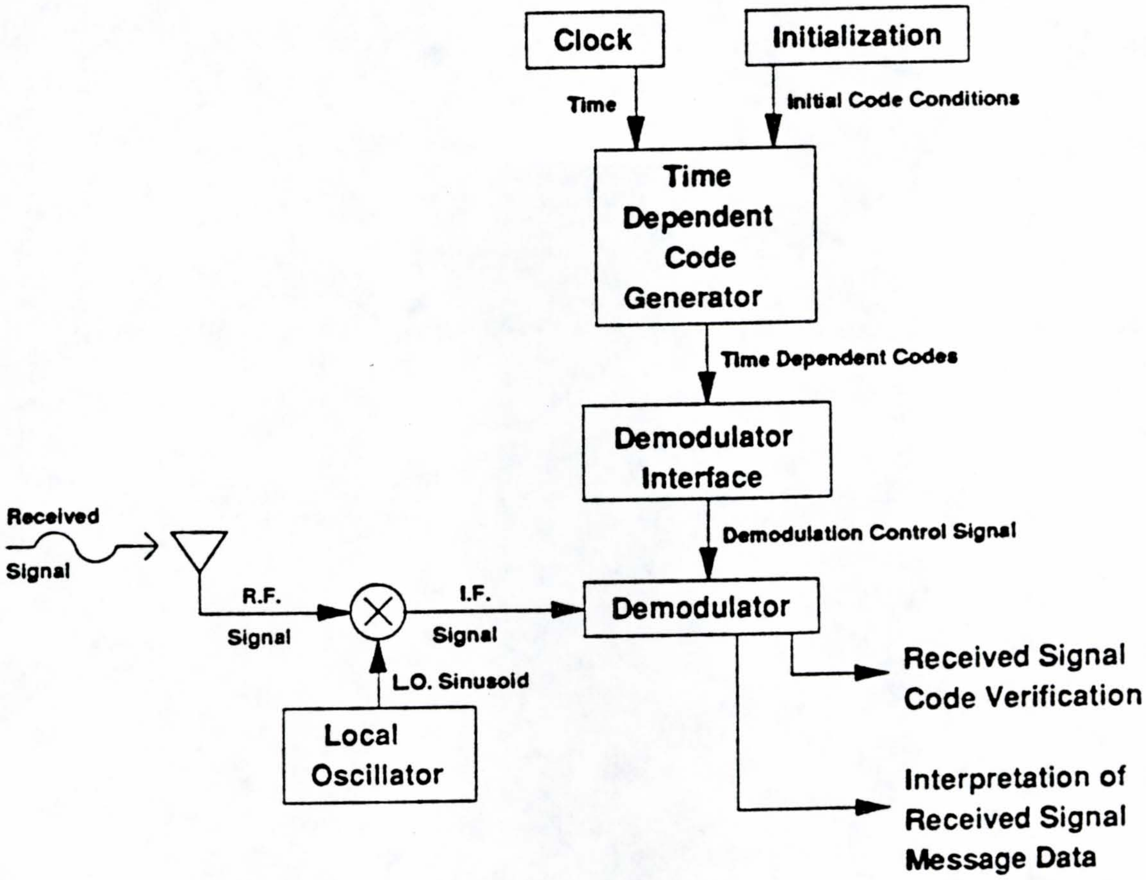


Figure 4-35. Block Diagram of a Receiver for a Communication System Employing Time Dependent Modulation Formats.

reference and code generation algorithm be common to both the demodulator and the modulator.

An interface step is used to convert the time dependent codes to the demodulator control. The demodulator uses various comparison techniques to determine whether the received signal or signals were modulated using the same time dependent coding format. If code verification is accomplished then demodulation, or interpretation of the received message data, is possible.

Again, processing is done at the most convenient I.F. frequency. The demodulator takes care of error correction and data post processing.

4.3.2.2 Examples of Communcation Systems with Time Dependent Modulation Formats. Examples of systems where time dependent coding is used in modulation are helpful in understanding the function of time dependent modulation formatting. Four illustrated examples follow. Illustrations decouple preliminary data encoding from the modulation process in order to emphasize the parts of the modulation processes which are time dependent by nature.

4.3.2.2.1 **Direct Sequence Spread Spectrum.** When applied to direct sequence spread spectrum communications, time dependent formatting and deformatting is represented by time dependent PN sequence spreading and despreading. An illustration of a time dependent code PN modulator is shown in Figure 4-36.

The PN sequence generator pictured applies an algorithm to the time dependent codes to produce a PN sequence. The direct sequence modulator multiplies the time varying PN sequence with the encoded data and then multiplies it by an I.F. carrier. The resulting direct sequence I.F. signal is converted to an R.F. signal and transmitted.

An illustration of a time dependent code direct sequence demodulator is given in Figure 4-37. The only way a received signal may be demodulated is for the direct sequence demodulator to have access to the same PN sequence as the modulator. When this is the case the received signal code will have been verified. It would then be possible for the receiver to interpret the information content of the modulated signal.

For the PN sequence to be present and the signal to be demodulated the system requires that the demodulator have the same time dependent code generation algorithm, the same time and the same initialization as the modulator. Time dependent modulation formats offer communications security but require time synchronization.

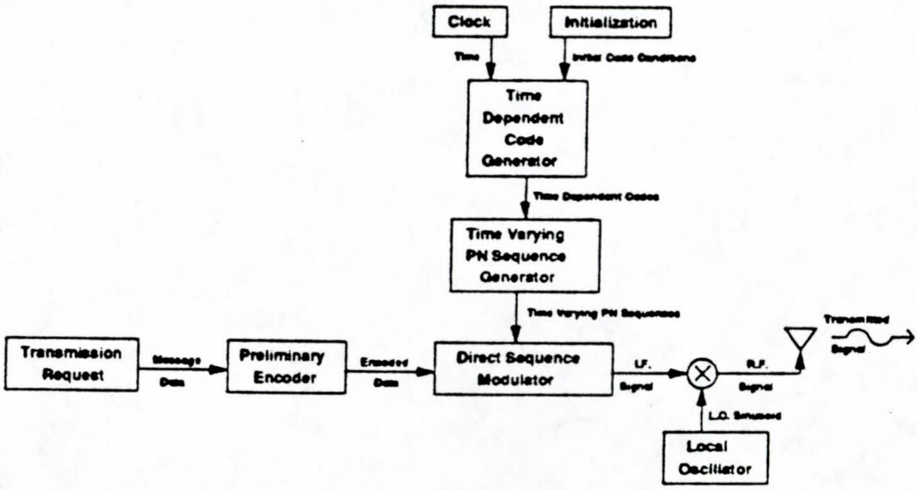


Figure 4-36. Block Diagram of a Transmitter for a Direct Sequence Spread Spectrum Communication System Employing Time Dependent PN Spreading Sequences.

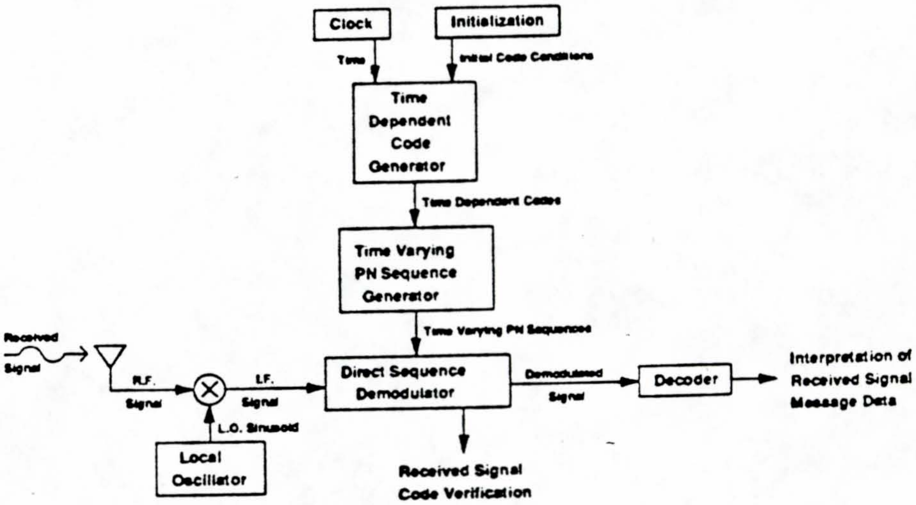


Figure 4-37. Block Diagram of a Receiver for a Direct Sequence Spread Spectrum Communication System Employing Time Dependent PN Spreading Sequences.

4.3.2.2.2 **Frequency Hopping Spread Spectrum.** A frequency hopping spread spectrum modulation system which employs time dependent formatting is shown in Figure 4-38. Time dependent frequency hop systems derive their ever changing hop patterns from the secure time dependent code generator. Frequency sequences serve the same purpose in frequency hop systems as PN sequences in direct sequence systems.

A time dependent frequency hop format demodulator is shown in Figure 4-39. As for direct sequence demodulation and PN sequences, frequency hop demodulation systems require that the frequency sequence be known before demodulation may take place. This means, in time dependent format systems, that the means for generating time dependent modulation codes must be available to the demodulator for communication to be successful.

4.3.2.2.3 **Pulse Width Modulation.** The use of time dependent coding for modulating a pulse width modulation process is illustrated in Figure 4-40. The demodulation system is given in Figure 4-41. Again, time coordination and shared coding initial conditions and algorithms make communication possible.

4.3.2.2.4 **Pulse Position Modulation.** Another modulation technique which may utilize time dependent formatting is pulse position modulation. The transmitter and receiver associated with this system are illustrated in Figures 4-42 and 4-43. Time dependent codes are used to vary, in time, the manner in which encoded data is pulse position modulated.

4.3.2.2.5 **Cascading Time Dependent Modulation.** It should be noted that these and possibly other time dependent format implementations may be cascaded to achieve multiple levels of communication security. In the cascaded time dependent format implementation one time dependent modulation format would serve as the "encoding" or "preprocessing" step for the time dependent modulation formats which follow it.

4.3.2.3 Impact of Time Dependent Formats on R.F. System Simulation and Stimulation. R.F. communication system simulation and stimulation require modulation and demodulation capability. This capability, for a given time dependent modulation format, requires a test tool with the same time dependent code generator, time reference and initial condition as the hardware it is testing.

4.3.2.4 Summary. Time dependent modulation formatting may be applied to any modulation technique. Time dependent formatting provides communications security but adds complexity to the modulation and demodulation systems. Successful communication through systems employing time dependent formatting requires time synchronization, common code generation algorithms and shared initialization conditions. Successful testing of systems which employ time dependent modulation formatting requires that these parameters be included in the testing tools.

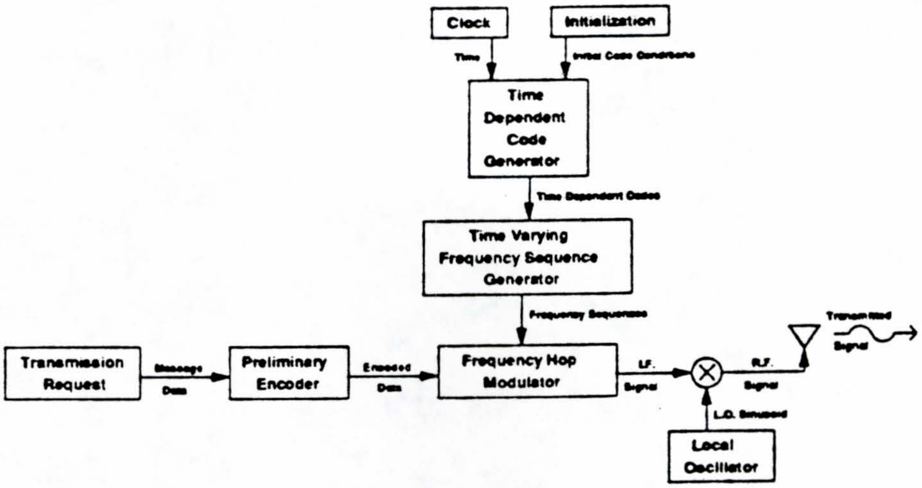


Figure 4-38. Block Diagram of a Transmitter for a Frequency Hopping Spread Spectrum Communication System Employing Time Dependent Frequency Sequences.

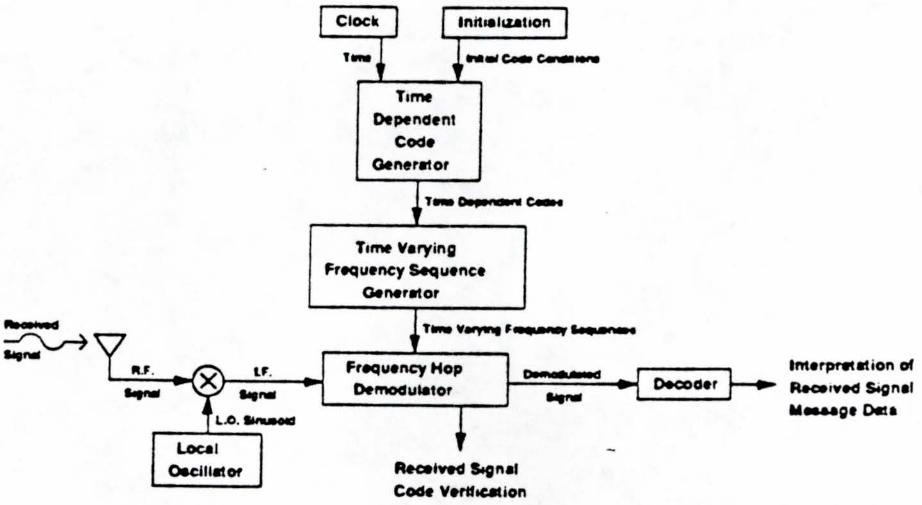


Figure 4-39. Block Diagram of a Receiver for a Frequency Hopping Spread Spectrum Communication System Employing Time Dependent Frequency Sequences.

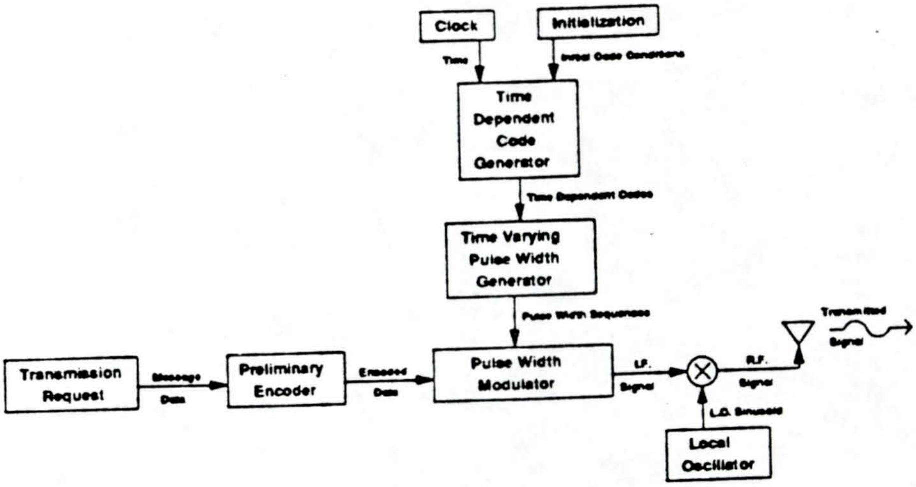


Figure 4-40. Block Diagram of a Transmitter for a Pulse Width Modulation Communication System Employing Time Dependent Pulse Width Sequences.

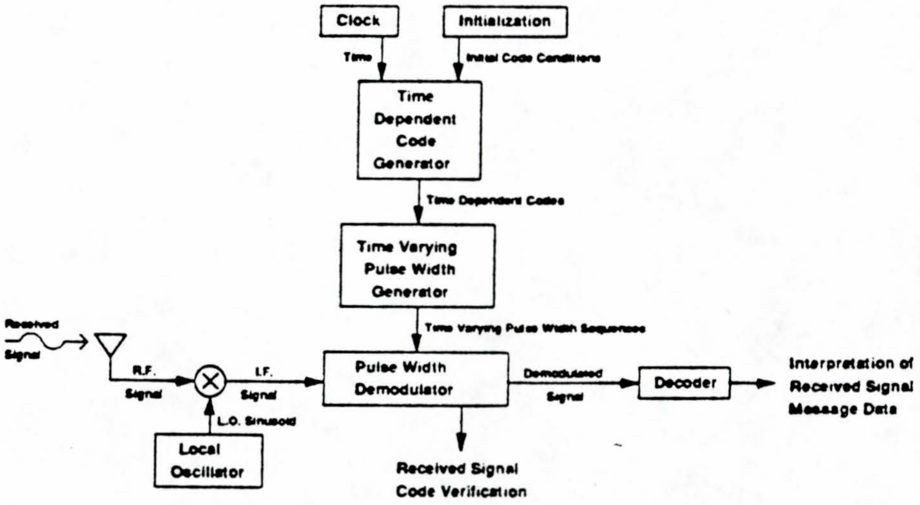


Figure 4-41. Block Diagram of a Receiver for a Pulse Width Modulation Communication System Employing Time Dependent Pulse Width Sequences.

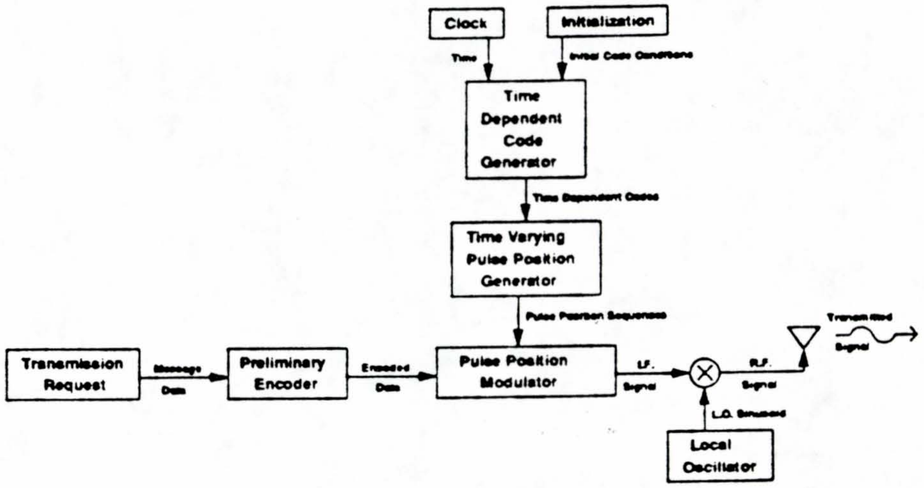


Figure 4-42. Block Diagram of a Transmitter for a Pulse Position Modulation Communication System Employing Time Dependent Pulse Position Sequences.

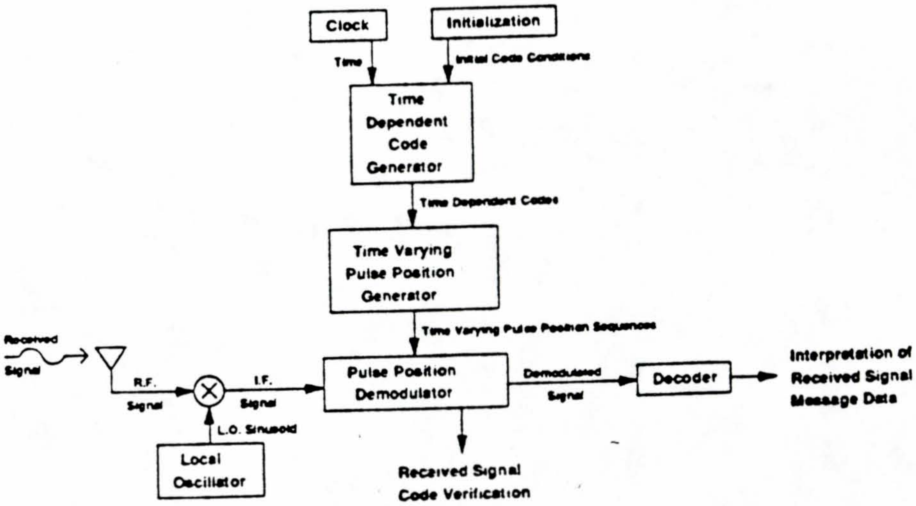


Figure 4-43. Block Diagram of a Receiver for a Pulse Position Modulation Communication System Employing Time Dependent Pulse Position Sequences.

4.3.3 Hardware Signal Generation

The purpose of this research is to support TESTS hardware development of the spread spectrum signal generation simulation tools, environmental simulation tools, jammer processor tools, and detector and demodulation tools. Tools refers to a combination of hardware, software, and software-driven hardware interface.

4.3.3.1 Approach. The rationale for the proposed implementation is to use the computer to generate the signal and perform calculations necessary to drive the required hardware. This may, in itself tax the speeds of the fastest computer. The hardware performs special tasks, in a serial manner, in either the digital or analog domain. The key feature is to use the optimum hardware configuration for the best/required processing gain. Computer simulations of real-time spread spectrum systems will typically require giga-flop speeds which hardware implementation will require less than 100MHz clock rates on the fastest components.

The proposed approach for signal generation of the NGIFF spread spectrum system is shown in Figure 4-44. It is composed of a computer which provides software generation of the message and provides hardware driver information on lines D_1-D_4. It is proposed that the message be developed to the necessary complexity as required by the NGIFF and compatible with real-time operation. The effective data rates associated with spread spectrum modulation will limit the role which software plays in signal generation.

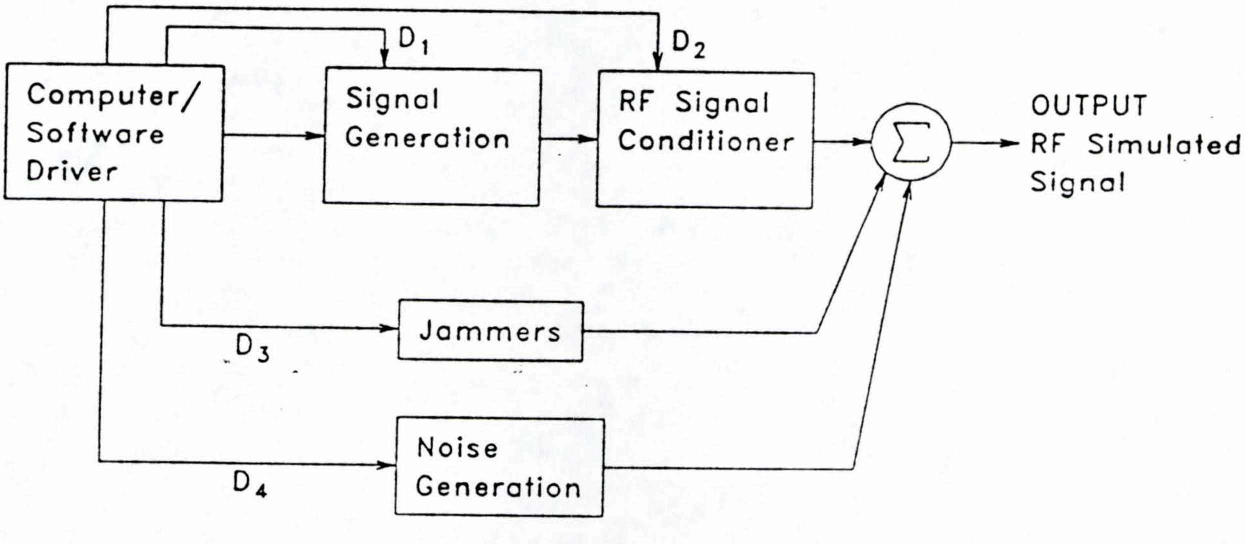


Figure 4-44. Signal Generation System Overview

The signal generator will format the signal per the NGIFF specifications. This will be accomplished using quadrature modulation hardware, PN direct sequence or frequency hopping generators for spreading, the proper encryption hardware, filter, mixing and other signal manipulation. The output from the signal generator should be a properly formatted, near ideal signal with waveform characteristics and data content requested by the controlling computer. The signal generator will be agile, i.e., can output arbitrary waveforms, within its own limitations and the driver inputs.

The RF signal conditioner, illustrated in Figure 4-45, will take the ideal signal and condition/change it via known inputs. There are a finite number of signal parameters which will model all environmental and second order effects, namely: (a) amplitude, (b) phase, (c) delay, and (d) frequency offset. Dispersion is a second order effect that can be modeled by implementing a combination of changes to the signal amplitude and phase.

The jammer should be a signal generator capable of generating pulsed signals, frequency hopped or direct sequence spread spectrum signals, or continuous wave jamming signals. The computer will drive the jammer.

The noise processor will be capable of generating white noise and possibly other types of signals to be determined in the future by the Navy.

The full simulated signal is provided as the output of the signal simulation software.

The detector-demodulation tools will undergo a reverse process, as shown in Figure 4-46. The simulated signal will be converted, de-encrypted and despread, base band converted, and analog-digital converted fro sampling. The computer will take the data and analyze the response for probability of error, message integrity, and other parameters of interest.

4.3.3.2 Research. It is believed that the highest risk is involved in the environmental simulation hardware tools. The ability to have arbitrary gain and phase dispersion, and offset delay has not yet been demonstrated. If a module could be developed inexpensively (<$5000), it would be possible to use multiple units to simulate multiple transmitters, fading, and multipath interference. It is proposed that this research be conducted to determine an optimal way to achieve these goals.

The work will involve specification of the required components, component integration, component design (if necessary), and testing of the environmental simulation module.

It is proposed to use variable gain amplifiers or attenuators for adjustable gain. Variable offset delay will be obtained by using one or more programmable SAW delay lines. Dispersion will be

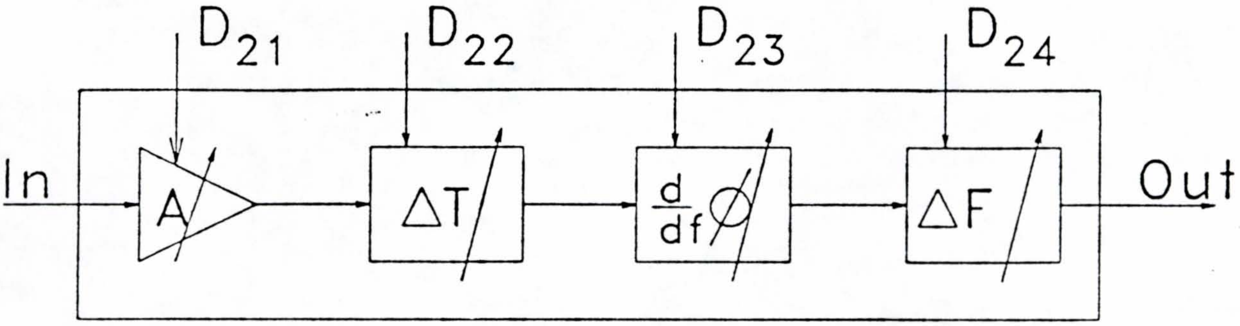


Figure 4-45. RF Signal Conditioner.

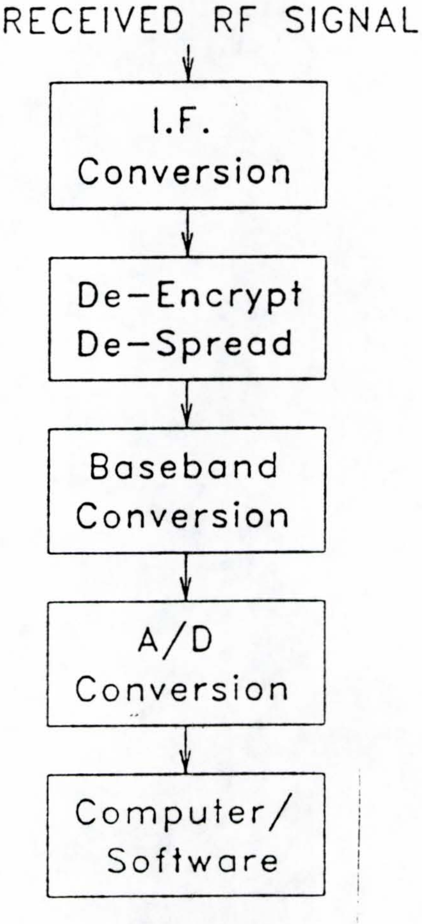


Figure 4-46. Detector-Demodulator Tools.

added using a programmable Acoustic Charge Transport (ACT) device of SAW. Frequency offset will be achieved using a mixer and frequency synthesizer. The integrated module will be tested for bandwidth, dynamic range, signal accuracy, and many other performance parameters of interest.

4.4 DESIGN RESEARCH STUDIES

As preparation for the TESTS Feasibility Assessment Report (CDRL A002), several design research studies were conducted to assess the impact of issues critical to the feasibility and tradeoff of TESTS design concepts. The derivations and preliminary conclusions are presented in the following paragraphs regarding the requirements for simulating multipath channel effects and for simultaneous simulation of multiple transponders and interrogators. In addition, a preliminary analysis of the data rate requirements between the TESTS host computer and the TESTS signal generation hardware is presented for the recommended TESTS concept in paragraph 3.4.3.

4.4.1 Simulation of Multipath Channel Effects

A quick look computer analysis was performed to determine the multipath propagation delay times associated with an ideal reflected path relative to the direct path, using a four-thirds radius round earth to account for atmospheric refraction.

Each signal transmitted by a sender may travel by two paths - one signal traveling directly between the platforms and the other undergoing a reflection off the earth. The signal traveling directly between the platforms arrives first and the reflected signal arrives a short time later.

The time difference between the direct and reflected signals is shown in Figure 4-47.

$$\frac{d-r_1-r_2}{c}$$

where c is the speed of light and d is given by

$$d-\sqrt{(R_E+h_1)^2+(R_E+h_2)^2-2(R_E+h_1)(R_E+h_2)\cos\theta}$$

d is known from radar and thus the above equation may be solved for θ. From the law of sines, r_1 and r_2 are given by

$$\frac{r_1}{\sin\theta_1}-\frac{R_E+h_1}{\sin(\alpha_1+90)}$$

and

$$\frac{r_2}{\sin\theta_2} - \frac{R_E+h_2}{\sin(\alpha_2+90)}$$

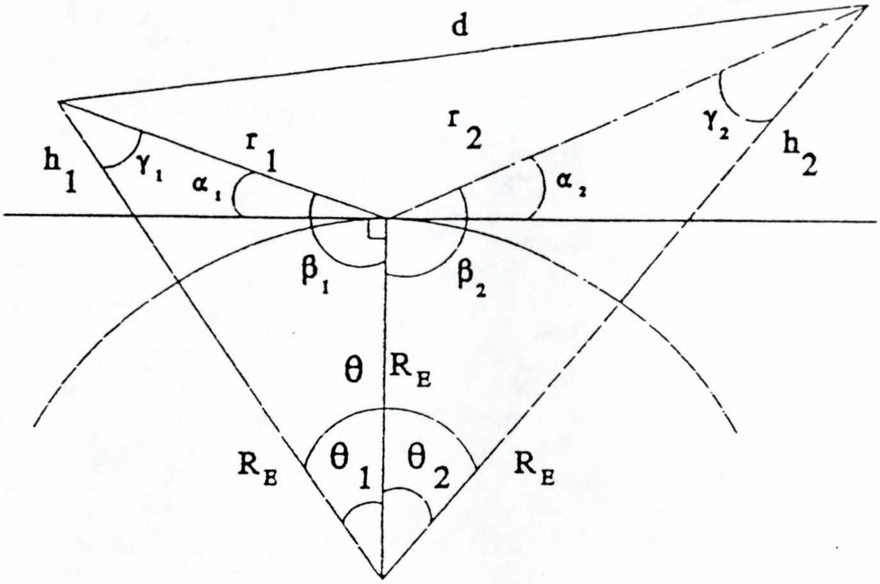


Figure 4-47. Multipath Geometry for Reflections from a Spherical Surface.

The angles, as shown in Figure 4-48, are found by writing

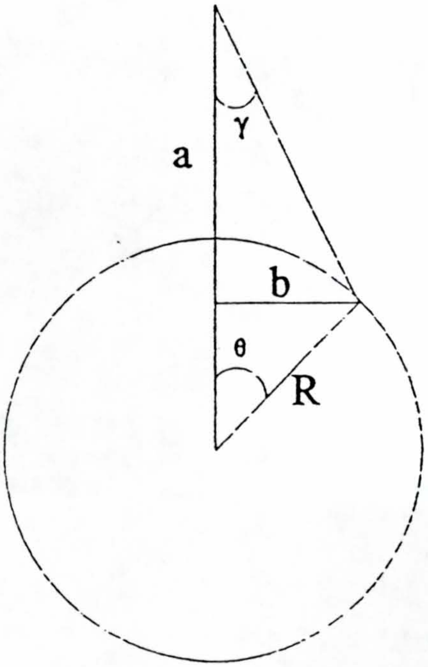
$$\gamma - \tan^{-1}\left(\frac{b}{a}\right) - \tan^{-1}\left(\frac{R_E\sin\theta}{R_E(1-\cos\theta)+h}\right)$$

which gives the expressions

$$\alpha_1 - 90 - \theta_1 - \tan^{-1}\left(\frac{R_E\sin\theta_1}{R_E(1-\cos\theta_1)+h_1}\right)$$

and

$$\alpha_2 - 90 - \theta_2 - \tan^{-1}\left(\frac{R_E \sin\theta_2}{R_E(1-\cos\theta_2)+h_2}\right)$$



$b - R \sin\theta$

$a - (R+h) - R \cos\theta$

Figure 4-48. Multipath Geometry - Gamma Components.

For reflection, $a_1 = a_2$ and thus setting $\theta_2 = \theta - \theta_1$ gives

$$\theta_1 + \tan^{-1}\left(\frac{R_E \sin\theta_1}{R_E(1-\cos\theta_1)+h_1}\right) - \theta - \theta_1 + \tan^{-1}\left(\frac{R_E \sin(\theta-\theta_1)}{R_E(1-\cos(\theta-\theta_1))+h_2}\right)$$

To find θ_1, the value of θ_1 is incremented in small steps until the left and right hand sides of the last equation are equal to within a given tolerance. The other angles may then be determined and used to find r_1 and r_2 and hence the time difference.

Figures 4-49 a, b, and c, present the results of this analysis as a function of platform separation distance for several combinations of platform altitudes. For the MK XII, the transponder reply has a pulse width of .45 microseconds +/- .1 microseconds, and a message range from 20.3 to 24.65 microseconds, while the non-encrypted interrogation message ranges from 3 to 21 microseconds. From this study, it is apparent that the difference in propagation delays may vary from less than a pulse width, to something greater than several pulse widths, or even an entire message, using the MK XII data formats as a reference.

Therefore, accurate simulation of multipath channel effects will require that in many instances, the reflected path signal will need to be transmitted separately from the direct path signal by the TESTS RF transmitter, with the same information and signal content, but with different channel effect parameters. This also requires an accurate adjustment of delay time, phase, attenuation/gain and frequency shift for the reflected signal, in order to simulate the interference phenomenon that would occur in the real world at the RF receiver.

4.4.2 Simulation of Multiple Transponders and Interrogators

MK XV TEMP Objectives require the testing of the System Under Test in realistic scenarios where many additional transponders and interrogators will be operating simultaneously. This leads to high interrogation rates if the SUT is a transponder, or high total reply rates if the SUT is an interrogator, which includes solicited replies plus Friendly Replies Unsynchronized in Time (FRUIT), as applicable. Interrogation rates on the order of five thousand per second, and reply rates on the order of thirty thousand per second are possible in these test scenarios.

As the number of IFF messages is increased (reply rate, or interrogation rate), the probability of message overlap at the receiver of the SUT likewise increases. It is considered important to be able to simulate this effect with high fidelity, in order to test important features of the IFF receiver and processor which are designed to deal with message garble, prioritization, synchronization, inter-symbol interference and the like. Therefore, the TESTS RF Transmitter must be able to generate multiple signals, and their associated multipath components, simultaneously.

Assuming that each IFF message is the same length and treating each response as an independent stochastic source, a parametric analysis was performed to determine the maximum number of message overlaps that occur within a cumulative probability of 99.9%. As used in this context, cumulative probability refers to the sum of the individual probabilities for 0, 1, 2, ... n message overlaps, where the individual probabilities are given by the first n successive terms of the binomial distribution function.

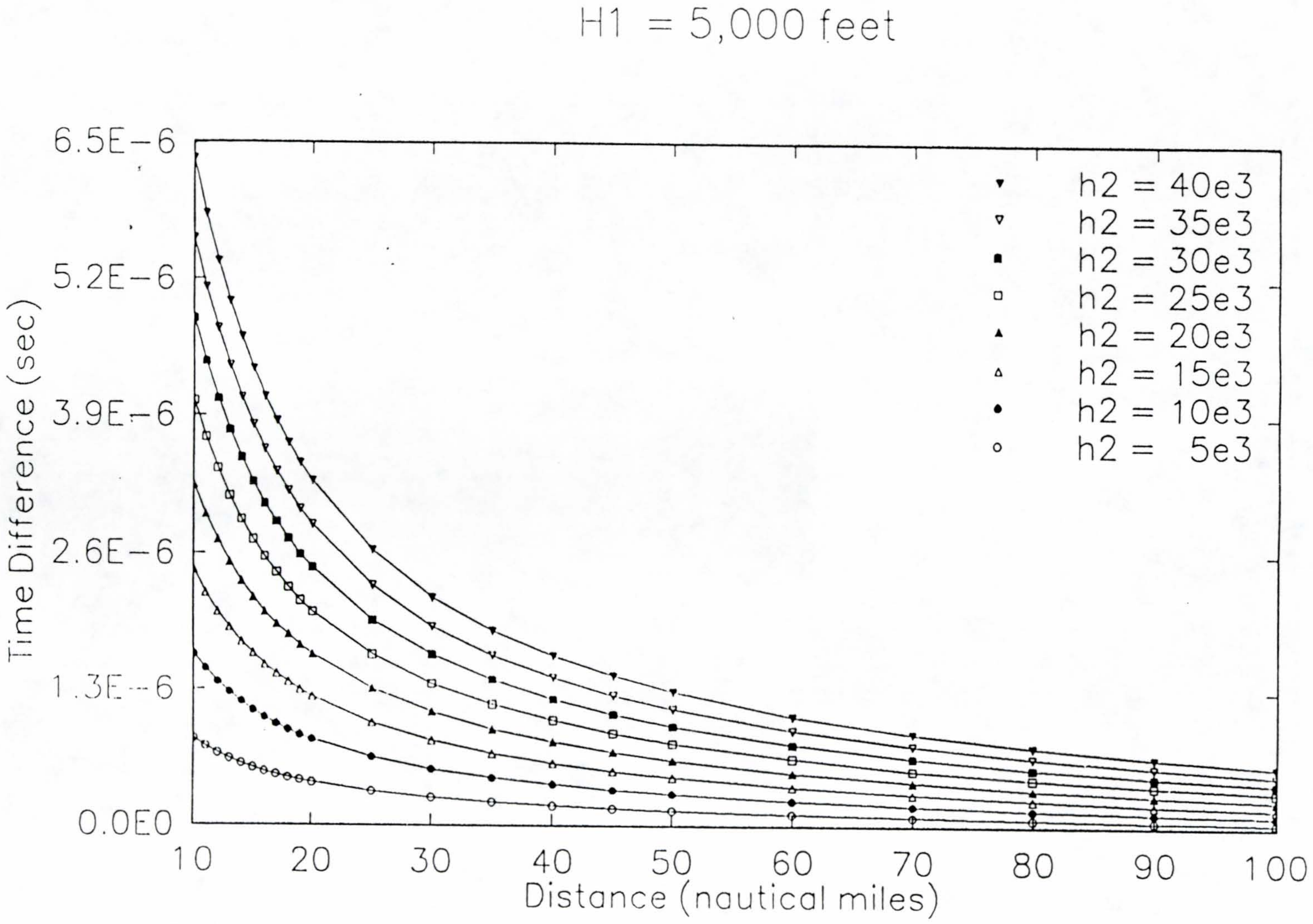
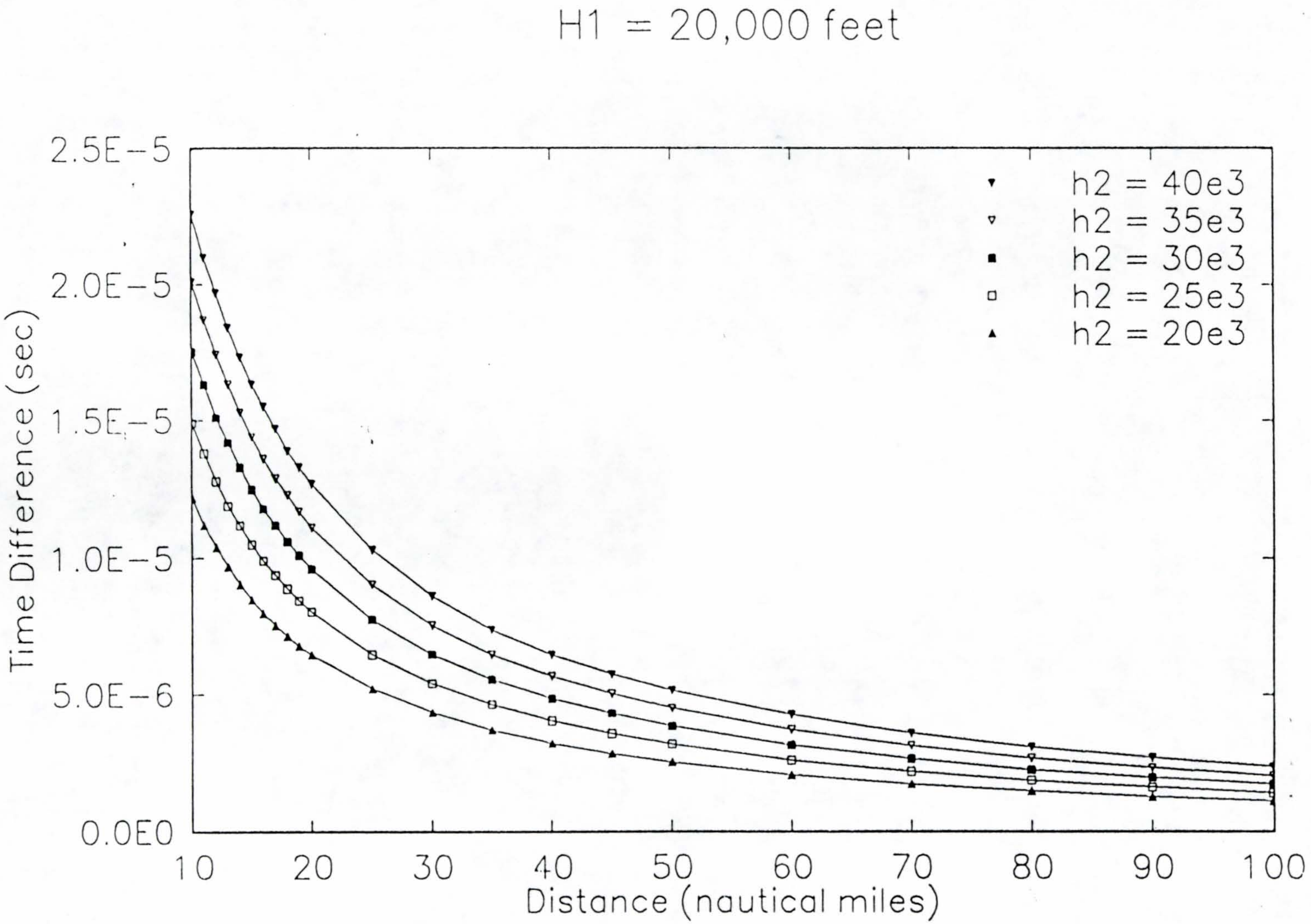


Figure 4-49a. Multipath Delay Times, H1 = 5000 ft.



H1 = 20,000 feet

Figure 4-49b. Multipath Delay Times, H1 = 20,000 ft.

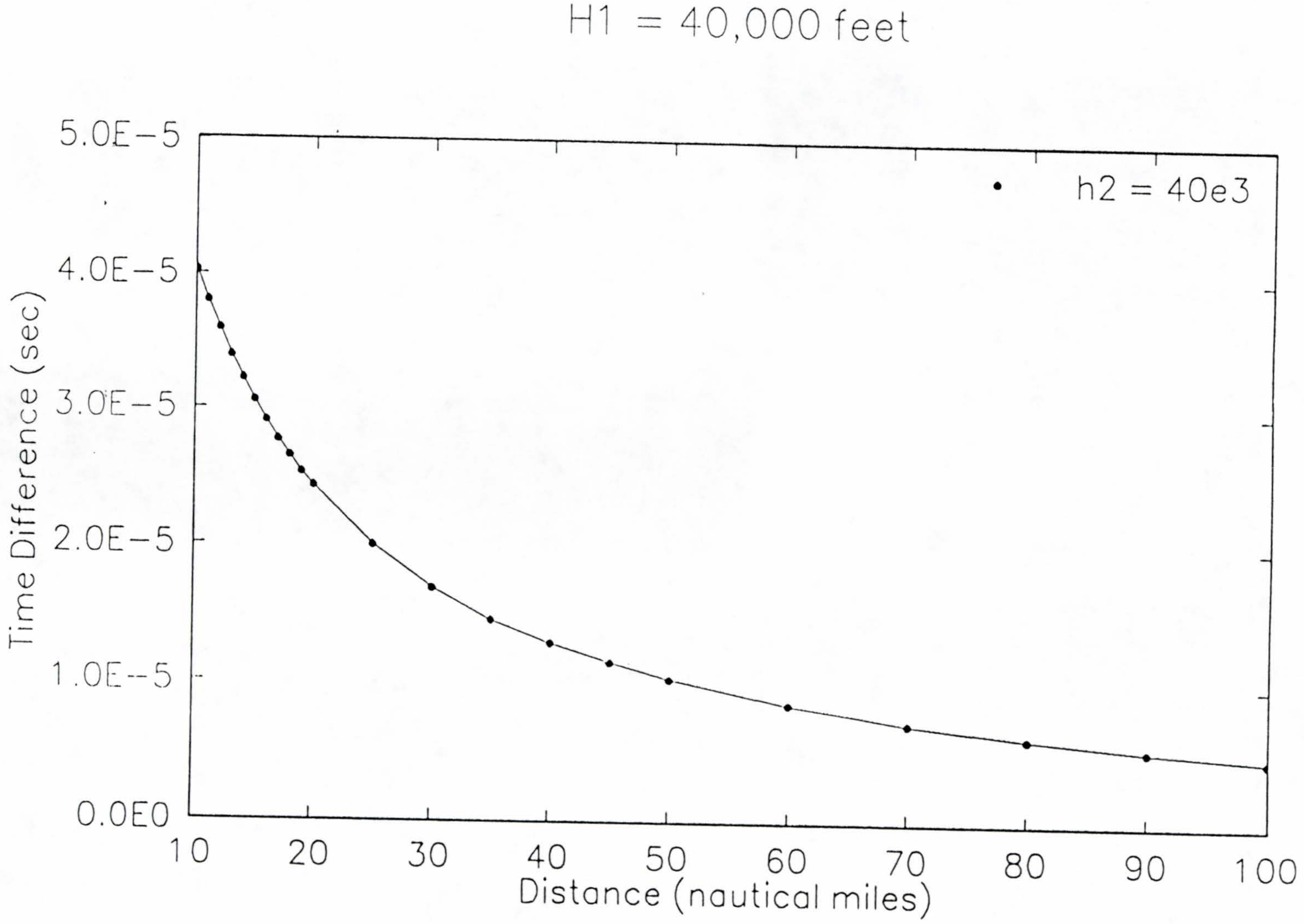


Figure 4-49c. Multipath Delay Times, H1 = 40,000 ft.

For example, given a message rate of n signals per second and a signal length of p microseconds, the probability of exactly k signals (or k - 1 overlaps) present at any given time is given by the binomial distribution

$$p(k) = \frac{n!}{k!(n-k)!} p^k q^{n-k}$$

where q = 1 - p. The probability of k or fewer signals at a given time is the sum

$$\sum_{i=0}^{k} \frac{n!}{i!(n-i)!} p^i q^{n-i}$$

For a given value of k, the sum is a function of the message rate n. Determining the value of n that makes the sum equal to 0.999 thus indicates that k signal generators will create the necessary number of overlapping signals 99.9% of the time for that message rate.

From a feasibility standpoint, TESTS must be able to provide at least the same number of independent emitters (k) as the number of simultaneous overlapping signals that we wish to simulate. Figure 4-50 summarizes the results of this study by plotting the number of emitters required (same as the number of overlapping signals) as a function of message rate for different values of message length. Thus, this figure provides a good indication of the number of independent TESTS RF emitters required to achieve a 99.9% level of fidelity over a range of parametric conditions. Note that in order to achieve a 100% level of fidelity (cumulative probability under the binomial distribution curve) the number of emitters would have to equal the total message rate for all cases. This is a good example of the law of diminishing returns at work.

Further analysis and refinement of these results will be performed, however, it appears that somewhere between 2 and 10 independent RF signal emitters will be sufficient to achieve the signal density environments required by the proposed test scenarios. Table 4-3 gives some examples relating to specific MK XII and MK XV message lengths.

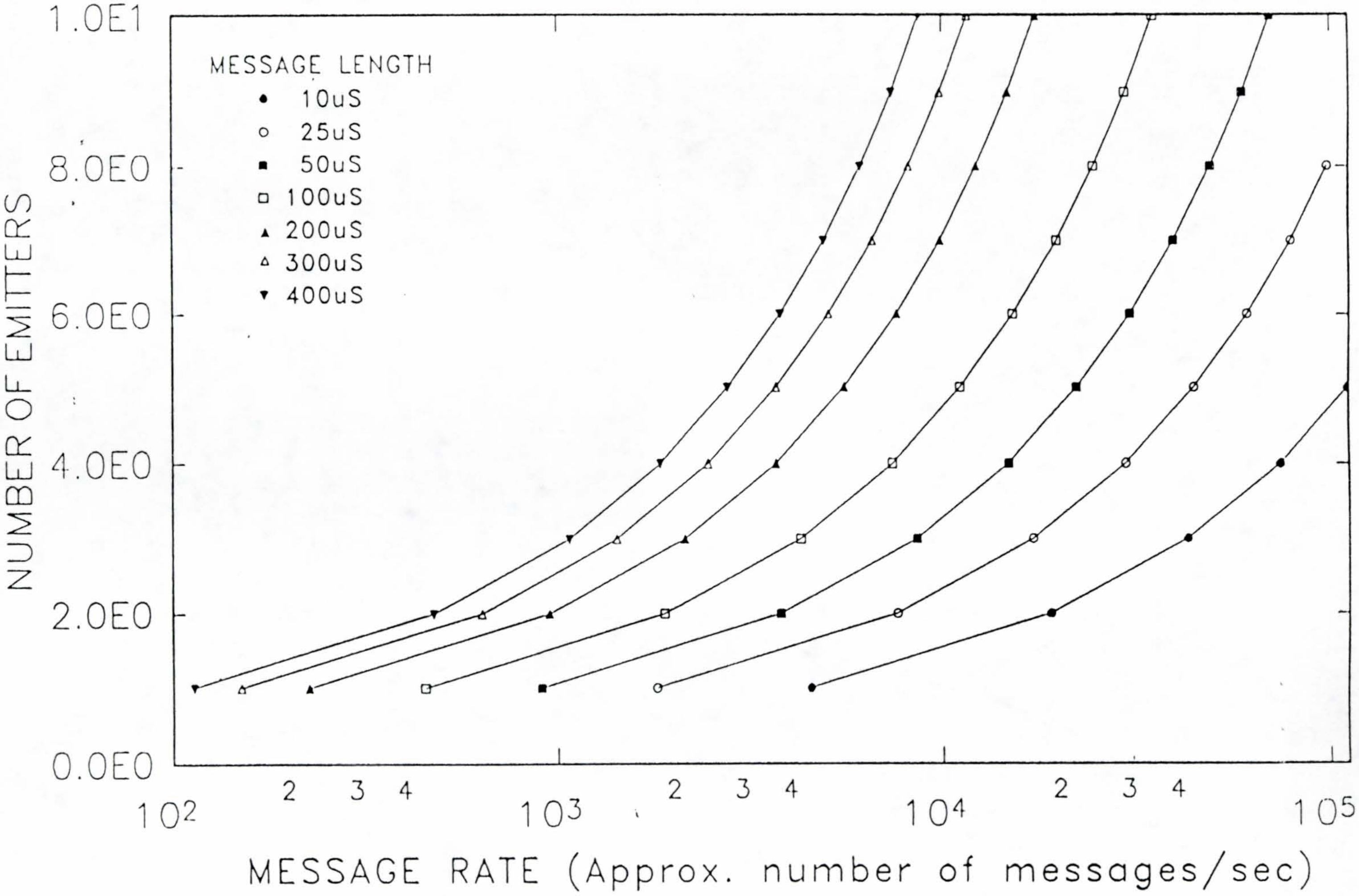
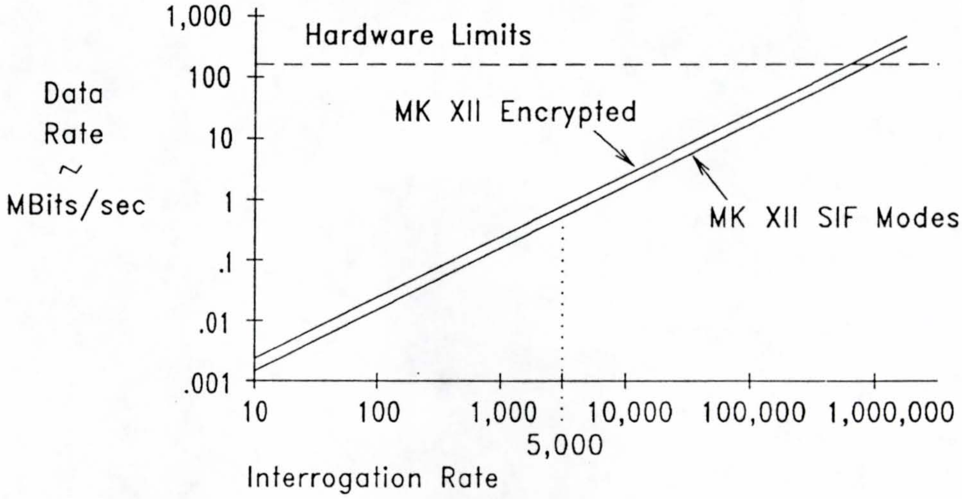


Figure 4-50. Number of Independent RF Transmitters Required for a 99.9% Confidence

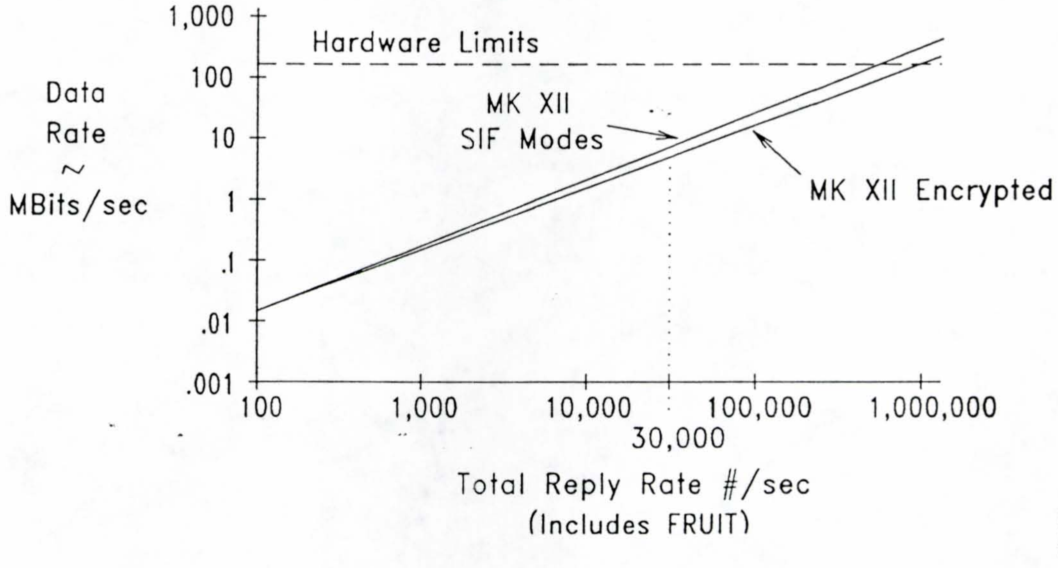
TABLE 4-3

EXAMPLES OF THE NUMBER OF TEST EMMITTERS
REQUIRED FOR MARK XII AND MK XV MESSAGES

Transponder = SUT



Interrogator = SUT



4.4.3 Data Rate Requirements for the Recommended TESTS Concept

The recommended TESTS Concept was presented in Figure 3-1. This concept utilizes a message level interface between the TESTS host computer and the TESTS hardware signal generators and receivers. It also utilizes programmable RF Signal Conditioner devices to insert channel effects into the signal paths.

The amount of data required to represent various IFF signals can be determined for both transmit and receive functions of the recommended TESTS concept as follows:

Channel Effects:

Direct Path:	Gain	8 bits
	Phase	8 bits
	Frequency Offset	8 bits
	Time Delay	32 bits
Bounce Path:	Gain	8 bits
	Phase	8 bits
	Frequency Offset	8 bits
	Time Delay	32 bits
		--------
		112 bits

Transmit MK XII SIF Mode Replies:

Message Type / Mode	16 bits
Message Data	16 bits
Channel Effects	112 bits
	--------
	144 bits / message

Transmit MK XII Non-Encrypted Interrogations:

Message Type / Mode	16 bits
Message Data	0 bits
Channel Effects	112 bits
	--------
	128 bits / message

Transmit MK XII Mode 4 Interrogations:

Message Type / Mode	32 bits
Message Data	16 bits
Channel Effects	112 bits
	--------
	160 bits / message

Transmit MK XII Mode 4 Replies:

Message Type / Mode	16 bits
Message Data	0 bits
Channel Effects	112 bits
	--------
	128 bits / message

Receive MK XII SIF Mode Replies:

Time Received	32 bits
Message Type / Mode	16 bits
Message Data	16 bits
	--------
	64 bits / message

Receive MK XII Non-Encrypted Interrogations:

Time Received	32 bits
Message Type / Mode	16 bits
Message Data	0 bits
	--------
	48 bits / message

Receive MK XII Mode 4 Interrogations:

Time Received	32 bits
Message Type / Mode	16 bits
Message Data	32 bits
	--------
	80 bits / message

Receive MK XII Mode 4 Replies:

Time Received	32 bits
Message Type / Mode	16 bits
Message Data	0 bits
	--------
	48 bits / message

Figure 4-51 presents a summary of the data rate requirements for the recommended TESTS concept, assuming the above data representations. This figure presents total data bus activity for TESTS transmit and receive functions, for two different test configurations.

The first configuration assumes that a transponder is the System Under Test (SUT), and the required data bus capacity is shown as a function of the simulated interrogation rate. For this

TABLE 3-2

EXAMPLES OF THE NUMBER OF TESTS EMITTERS REQUIRED FOR MK XII AND MK XV MESSAGES

MESSAGE TYPE	APPROXIMATE MESSAGE LENGTH	MESSAGE RATE	# OF EMITTERS REQUIRED
(U) MK XII MODE 3A INTERROGATION	10 u sec	5000/sec	1
(U) MK XII MODE C INTERROGATION	25 u sec	5000/sec	2
(U) MK XII MODE 4 INTERROGATION	75 u sec	5000/sec	2
(S) MK XV INTERROGATION	(classified)	5000/sec	
(U) MK XII MODE 3A REPLY	25 u sec	30000/sec	4
(U) MK XII MODE C REPLY	25 u sec	30000/sec	4
(U) MK XII MODE 4 REPLY	5 u sec	30000/sec	2
(S) MK XV REPLY	(classified)	30000/sec	

Figure 4-51. Summary of Data Rate Requirements.

analysis it was assumed that one IFF reply is generated by the SUT for each interrogation generated by TESTS.

The second configuration assumes that an interrogator is the SUT, and the required data bus capacity is shown as a function of Total Reply Rate, which includes solicited replies as well as Friendly Replies Unsynchronized in Time (FRUIT) that are generated by the TESTS simulation. For this analysis, it was assumed that a constant 100 interrogations per second were generated by the SUT, so that a minimum of 100 replies per second are expected.

As these analyses show, data rate requirements for the Recommended TESTS Concept are within the capacity of commercially available (150 M Bits/sec) data busses for interrogation rates up to 72,000 per second, and for total reply rates up to approximately one million per second for all MK XII message formats.

5.0 CONCLUSIONS

The Navy's active support and cooperation ensured that the feasibility assessment was both comprehensive and thorough. The TESTS project team was permitted to study all relevant documentation and visit all pertinent facilities. Seemingly unsurmountable technical obstacles diminished in difficulty as the team's knowledge increased. The essential conclusion is that TESTS will enable the Navy to address the five primary simulation TEMP objectives identified for simulation and achieve accurate test results with high levels of confidence. Additionally, the project team is confident that TESTS can greatly improve the statistical confidence and accomplishment of a number of secondary TEMP objectives. The recommended conceptual design presented in this document optimizes the TESTS to achieve identified TEMP objectives for an advanced IFF system utilizing a spread spectrum format, as well as the current MK XII system. Moreover, the simulation test tool should provide extremely important insight for all future avionics and electronic subsystems using a spread spectrum format.

The concepts proposed herein for the TESTS represent a significant, yet practical, advancement in the state-of-the-art simulation environment for DT&E and OT&E testing of both current and proposed IFF systems. A systematic research and development effort is required to realize the potential of the TESTS conceptual design. These efforts are characterized by the discussion of research activities in Section 4.0. The IST/UCF TESTS project team will follow accepted systems engineering practices to guide TESTS development and control technical risk.